# A Naturally Powered Building At A Typical UK River

by

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# abstract

The efficiency of energy supply and demand in the residential sector is of great importance in the UK. Using renewable sources of energy such as water, to supply the demand of some buildings, has proved to be a proper energy strategy. In terms of this dissertation, an old watermill has been upgraded. A "Kaplan" turbine has superseded the old wooden wheel of the mill and the building is been renovated to accommodate apartments of different occupancy. Then, it is assumed that it is placed into two rivers of different average flow rate. The study aims to evaluate how much energy could be supplied to residential buildings by a typical UK river.

Results showed that installing a turbine in a building should be thought thoroughly, as there must be sufficient water in the location of the installation. Buildings of 300 $m^2$ occupied area can be served by rivers of mean flow rate of 5.40 $m^3/s$, while rivers of low mean flow rate, such as 1.0 $m^3/s$ provide only a small amount of the energy demand. Issues like cost of installation and maintenance of the turbine are also quoted and discussed.

# acknowledgements


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# chapter 1
# introduction

## 1. 1 aim of study

Water has always been a renewable energy source, which plays an important role in the technological development of the world's rural areas. Watermills represent one of the most significant devices of all time. The power of the moving water operates machinery, and then the potential energy in the water is converted to kinetic energy, which is transmitted to a different form of kinetic energy to fulfill any needs.

In terms of the study an existing watermill is being upgraded to fulfill residential needs. Two cases are examined. In the first one the building has two apartments of 146 $m^2$ and in the second it accommodates six flats of an average area of 40 $m^2$ each. The building is then assumed to be placed into two rivers of different mean flow rate. The scope of the study is to evaluate whether a typical UK river can supply the energy demand of the building.

## 1.2 methodology

Two cases of an old Hampshire watermill, the Whitchurch Silk Mill, are examined. The first one is that the three-storey structure will be separated into two apartments in order for two four-member families to live in. The second case is that the whole building will be divided into two different flats in each floor to accommodate 6 couples. Both buildings were placed in two rivers, with different average flow rates, in the southern part of Britain. Dever River at Bransbury and River Itchen at Highbridge and Allbrook have been chosen because of their different average flow rates.

After receiving data for the study area of the rivers, it is essential that a turbine should be selected to replace the wooden wheel of the mill. After that, the energy available to the turbine from each of the rivers is calculated, so as to find the supply.

Having the supply, it is vital that we find the demand of each mentioned case. To do that, each case is modeled in TAS building simulation program. The results from TAS give the energy that each building requires to fulfill the needs of their occupants.

## 1.3 report structure

Following the introduction, this project continues with a literature review about the old watermills in the British Isles and how they were taking advantage of the power from water in the past. Types of water wheels and water turbines and their characteristics are also presented.

In Chapter 3 the area that the watermill is going to be placed is found and analyzed and according to the characteristics of the flow rate of the rivers and the head of installation, the type of the turbine is decided. Therefore, the supply from the river is known.

Chapter 4 refers to the demand of the building. Two cases are examined for the building. In the first one, the watermill will accommodate two apartments for two four-member-families and in the second one there will be six apartments for six couples living in them. Hence, the demand of the building depends on the occupancy and the area of the apartments. Following the designs of the buildings, the modeling of them takes place.

In Chapter 5 the results, as to which extend the rivers could fulfill the needs of the two buildings, are drawn. A discussion is then quoted.

Finally, Chapter 6 includes the overall conclusions.

# chapter 2

# literature review

## 2.1 introduction

Approximately 80% of planet Earth is covered by water. Water is always on the move. In every river and creek, water flows under the force of gravity. Snow or rain falls from highlands and mountains forming little rivulets and streams, which they conclude to large rivers and later to oceans. Water from the surface of the rivers, lakes and oceans evaporates and comes back to the atmosphere as visible water vapour. The unseen water condenses from the air to form clouds, rain, snow or hail. Rain and snowfalls bring fresh water back to the headwaters of the streams, and the "hydrologic cycle" is completed. The hydrologic cycle brings continuous supplies of water to the uplands ensuring that the flowing water will always be available to our planet. (Re-Energy.ca 2008).

Renewable source as it is, water plays a vital role in the technological development of the world's rural areas. The force of moving water can sometimes exceed several million horsepower. It is this power, that human attempt to harness over time and use it for reducing the working load and later for generating electricity (Re-Energy.ca 2008).

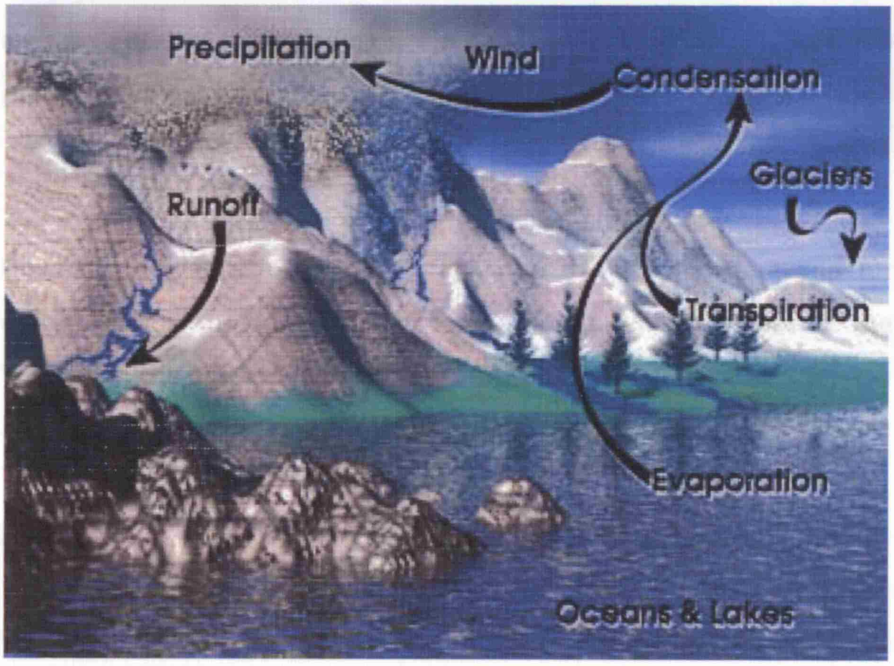



*Figure 1: The Water Cycle. SOURCE: http://www.sciencemaster.com/jump/earth/water_cycle.php*

## 2. 2 stored energy and available power from water

During the past and until the nineteenth century, the kinetic energy of the water was utilized to drive machines. This potential energy of water at a height is called the stored energy, and its value is given by the equation below (Boyle 2004, 155):

$$PotentialE\ nergy = M \times g \times H(J) \tag{1}$$

Where:

$g = 9.81 m/s^2$ : the gravitational acceleration

$M$ : $kgs$ of water (or anything else)

$H$ : $m$ that $M$ $kgs$ of water will be raised vertically against the gravitational pull of the Earth

The power supplied by the falling water can be easily estimated from the equation above. This will depend on the flow rate of the falling water, the number of cubic meters per second $(Q)$. The mass of a cubic meter of water is $1000\,kg$, thus the mass of a cubic meter of water falling per second is $1000 \times Q(kg/s)$, so the power supplied is (Boyle 2004, 156):

$$P = 1000 \times Q \times g \times H(W) \tag{2}$$

However, any form of energy is lost due to frictional drag and turbulence. Hence, energy losses should be taken into account when calculating the output power. Therefore, the equation has the final form below (Boyle 2004, 156):

$$P = 1000 \times n \times Q \times g \times H \tag{3}$$

Where:

$n$: % efficiency of the generator

$H$ : $m$ of the effective head, which is less than the actual one

# 2.3 head of installation

The head of a site has been already mentioned in the previous paragraph. What is it exactly the "head of a site", though?

Let us take for example two hydroelectric plants, one being small volume of high-speed water from a mountain and the other huge volume flow of a slowly moving river. Both of them can have the same power output. This is because the effective head of the site acts differently in each of the plants. There can be high-, medium- and low-head installation in a site. There are no strict boundaries for each one of them and many times the values depend on the civil engineering work and the choice of turbine. However, as a rule of thumb an effective head of up to 100 m implies a high-head, and less than 10 m a low-head (Boyle 2004, 162).

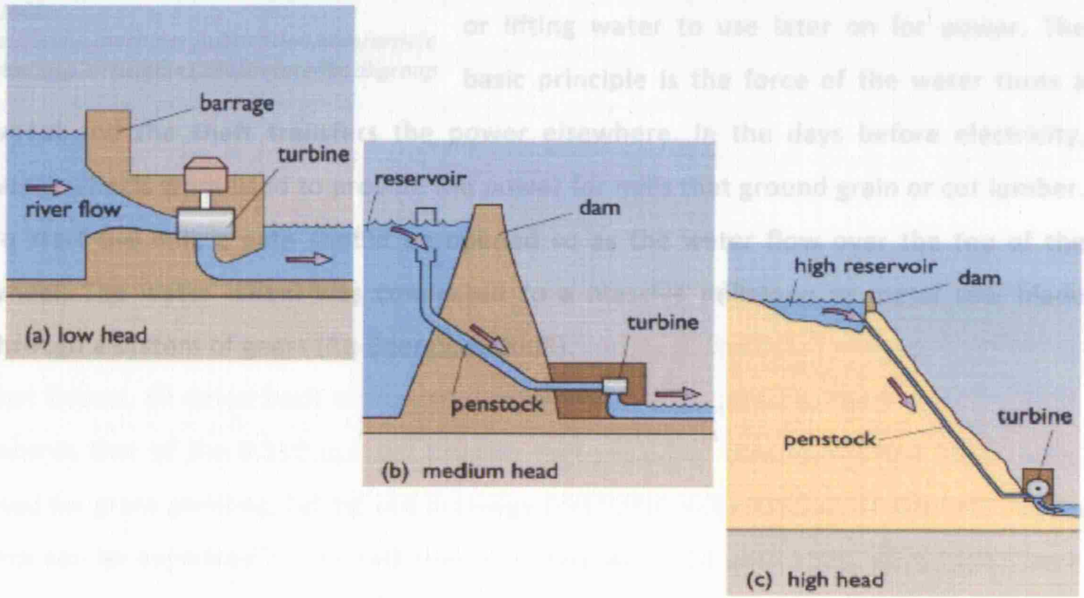



*Figure 2: Types of Hydroelectric Installation. SOURCE: Boyle, 2004*

In the low head plant, there is little storage capacity compared to the medium one, and the flow rate is what affects the given power. In a medium-head plant, the supply is always adequate and meets every demand in all seasons, as the reservoir behind the dam is very large. Last but not least, in a high-head installation, the flow needed for providing with the appropriate power is much smaller than that of a low-head plant (Boyle 2004, 163).

## 2. 4 water power in the past

Harnessing water and use its power to move a water wheel was one of the earliest energy sources. During the past years, it was used to reduce the work load of people and animals. The earliest machines being used to raise water into an aqueduct utilizing water's flow, was called Noria. Noria consisted of a water wheel, paddles placed on the rim, as well as clay jars. The paddles dip into the water and the jars raise water for irrigation. The wheel rotates as the jars, which discharge the water into an irrigation channel (Boyle 2004, 157).

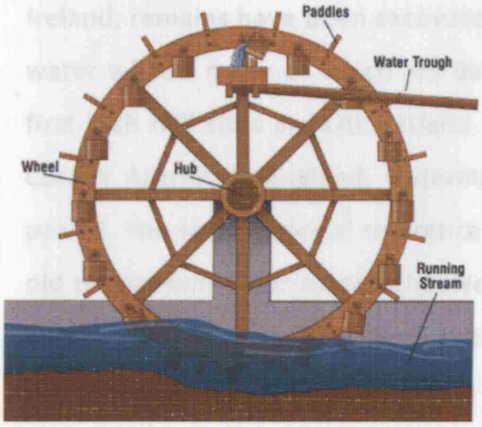


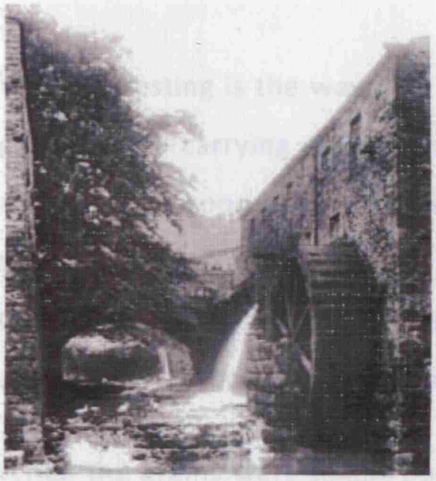

*Figure 3: Noria, the earliest machine.*
*SOURCE:*
*http://www.machinerylubrication.com/article_detail.asp?articleid=1294&relatedbookgroup*

Water is useful for irrigation as above or power or lifting water to use later on for power. The basic principle is the force of the water turns a wheel and the shaft transfers the power elsewhere. In the days before electricity, water wheels were used to provide the power for mills that ground grain or cut lumber. To start the mill, a gate should be opened so as the water flow over the top of the wheel. The water wheel was connected to a massive millstone or metal saw blade through a system of gears (Re-Energy.ca 2008).

## 2. 5 watermills in the British Isles

Remnants of old watermills were found all over the world. Middle East, Greece, Scandinavia, Britain and Ireland were countries that used them in abundance. In Ireland, remains have been excavated of about a hundred of small mills with horizontal water wheels many of which are dated back to the early medieval period. Two of the first Irish mill sites are Little Island, County Cork, and Nendrum, on Strangford Lough, County Antrim. In England, watermills were first introduced during the middle Saxon period. The first historical reference is to a watermill at Chart, however, remains of an old timber-build, horizontal-wheeled watermill of the early eighth century were found in Ebbsfleet, Kent, in 2002. Both the mill in Ebbsfleet and in Ireland, have been worked by salt water. In the ninth and tenth century, watermills proved to be used widespread. Mills were excavated at Tamworth, Staffordshire and on the north bank of River Tyne, at Corbridge, Northumberland. These timber, horizontal-wheeled mills are dated back to the late Saxon period. Other horizontal-wheeled mills are found at Worgret, Dorset and Wellington, Herefordshire. However, not only horizontal-wheeled mills were used. Documentary information has shown that from the thirteenth century, vertical-axis waterwheels were used (Watts 2006).

Among the oldest watermills that have survived in UK is that of Cistercian abbey of Fountains, in North Yorkshire, Pile's Mill, at Selworthy, in Somerset and Sheffield Mill in East Sussex, all dated back to the mid and late sixteenth century. The Domesday Book records that of the 9,250 manors existing that period of time, 3,463 had 5,624 mills, used for grain-grinding, fulling and drainage (HISTORIC HEREFORDSHIRE ON LINE 2008). This can be explained by the fact that in its heyday, 1650 until 1800, water mills were used by many industries, as output power of up to sixty horse-power could be developed (approximately 45 kW) (Boyle 2004, 158).



Left: *Allerford, Piles Mill 1931, Somerset.*

Above right: *Hawes, the Mill 1900, Yorkshire.*

Below left: *Bovey Tracey, The Mill 1920, Devon.*

Below right: *Carshalton, Mill Wheel Hall c1955, Greater London.*

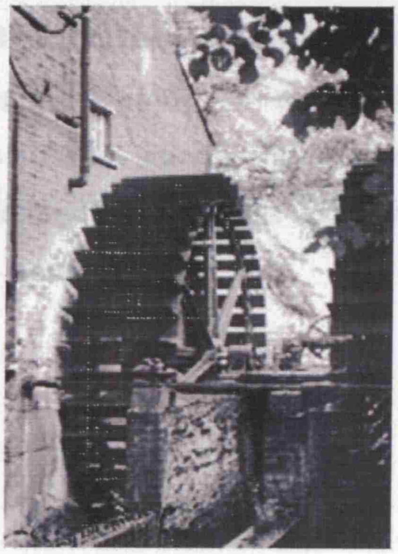


*Figure 4: Mills in different areas of UK. SOURCE: http://www.windmillworld.com/shop/waterfull.htm*

## 2. 6 operation of a watermill

Very interesting is the way that watermills were operating. That period of time, people were carrying grains in sacks from their farms to the mill, using horses and carts. As soon as these grains arrived to the mill, they had to be unloaded and carried to the top floor by the "sack-hoist". Pulleys and gears powered by the water wheel, helped the "sack hoist" to operate, by lowering its chain from a mechanism stood out from the top of the mill (Norfolk Mills 2008).

When the grains were finally delivered to the top floor, they were emptied into a "hopper" or a bin to be guided into the millstones. The grain fell from the bin into a smaller hopper, being placed on the top of the stones (on the first floor), and then reached the centre of the stone by a movable wooden inclined surface, called "slipper". The grains were then being grinded (Norfolk Mills 2008). All the power for this procedure was provided by the water wheels.

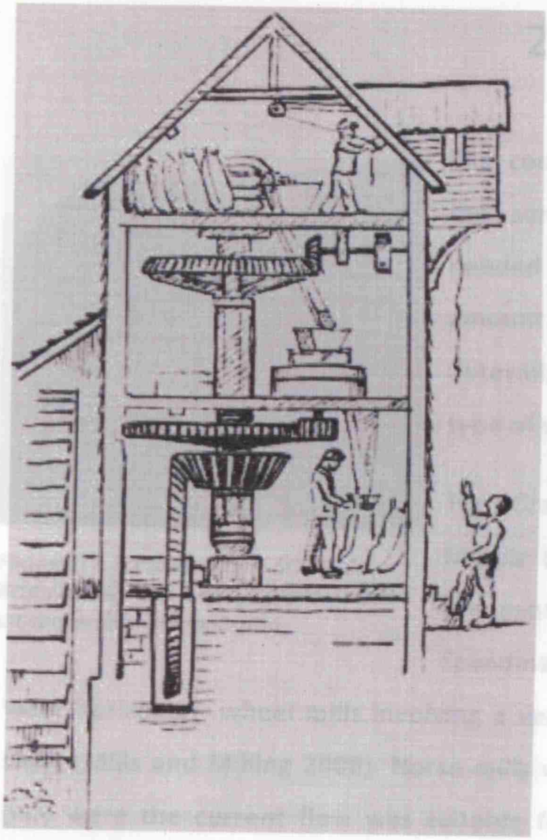


*Figure 5: Pippa Miller's drawing of a typical Norfolk watermill. SOURCE: http://www.norfolkmills.co.uk/watermill-machinery.html*

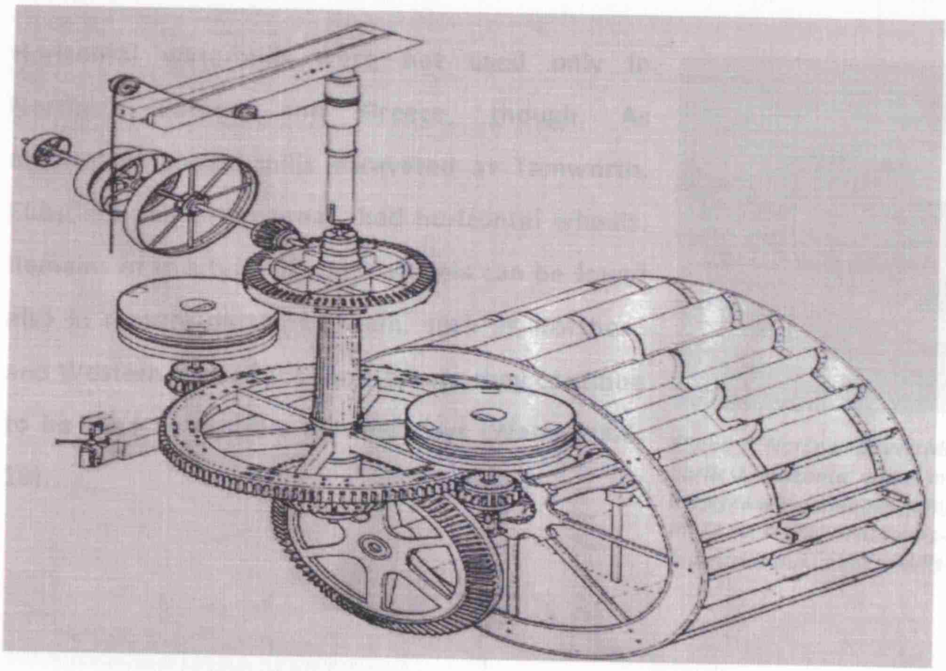


*Figure 6: Watermill gearing system SOURCE: http://www.norfolkmills.co.uk/watermill-machinery.html*

Figure 7: A horizontal mill. SOURCE: http://www.ict.mic.ul.ie/content/niallosullivan/web/watermills.htm

## 2. 7 types of water wheels

The construction of a watermill has an impact on the surroundings, as it depends on the water needed to be impounded whenever required. The amount of flow and the height of the head or fall determine the power available and indicate the type of water wheel that can be used.

The first watermills made their appearance in Middle East during the first two centuries BC and a few centuries later in Northern Europe, specifically Scandinavia, named as Norse or Greek mills. They were horizontal- wheel mills involving a vertical water wheel fastened to a horizontal shaft (Mills and Milling 2008). Norse mills were mostly used by peasants for grinding, only were the current flow was suitable for this process (Encyclopedia BRITANNICA 2008).

Horizontal watermills were not used only in Northern Europe and Greece, though. As mentioned above, mills excavated at Tamworth, Ebbsfleet and other areas, had horizontal wheels. Remains of this type of water wheels can be found also in remote parts of Britain, such as Northern and Western Isles of Scotland, where they continue to be used by crofters till nowadays (Watts 2006, 19).

Figure 8: Norse or Greek Mills, the earliest horizontal water mills. SOURCE: http://www.dkimages.com/discover/Home/Architecture/Factories-and-Industrial-Bui.../Mills/Mills-1.html

Figure 9: A vertical mill. SOURCE: http://www.ict.mic.ul.ie/content/niallosullivan/web/watermills.htm

Because of the fact that horizontal water wheels were terribly inefficient in transferring the power of the current to the milling mechanism, they were replaced by waterwheels of a vertical design (Mills and Milling 2008).

By the end of the eighth century, the vertical water wheels were spread slowly across Europe to finally reach the British Isles. These wheels were taken power from a horizontal shaft, and then transform it to a vertical one, so as to force the millstones inside the building. Gears were necessary to do this job. There are three types of vertical water wheels, depending on the height of the fall of water: undershot, overshot and breastshot (Watts 2006, 19).

The undershot wheel is the earliest type of water wheel. The lowest blades are dipped into the flowing stream and the pressure of the water flow drives them. The wheel then is pushed round. This type of wheel was used for fulling and corn milling. It can be used in any stream, as it does not require a large head of water, and the civil engineering work for its installation is negligible (Power in the Landscape 2008). The only disadvantage is that in case of flooding, the motion of the wheel may be hampered, as the water backs up (Boyle 2004, 159).

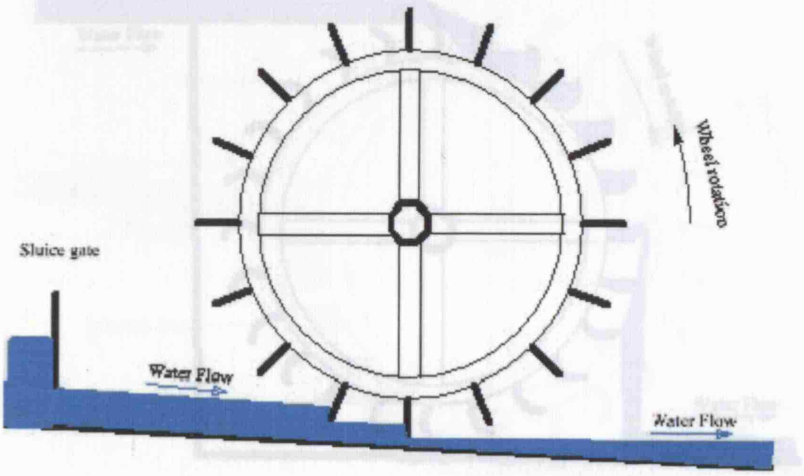



Figure 10: An Undershot Water Wheel. SOURCE: http://www.powerinthelandscape.co.uk/water/water_wheels.html

Characteristics of an undershot water wheel are presented in the following Figure.

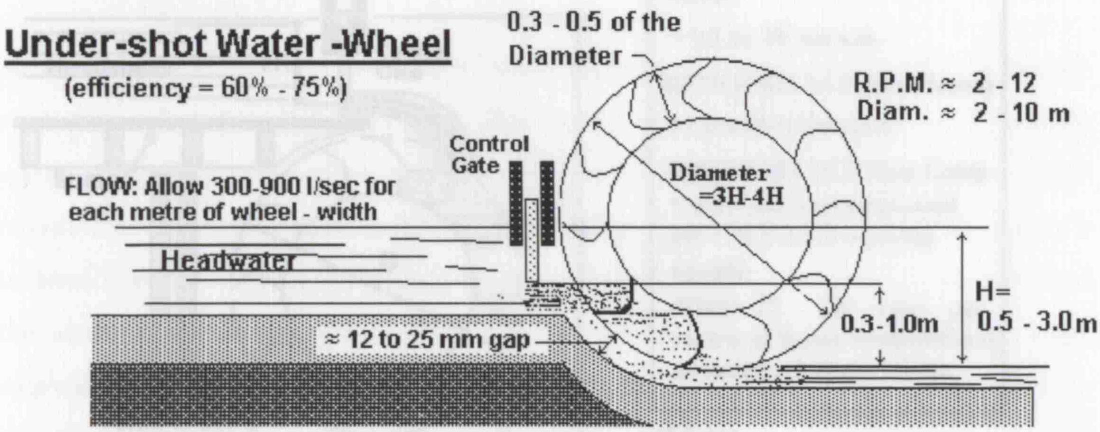



*Figure 11: Characteristics of an undershot water wheel. SOURCE: http://ipc6.permaculturewest.org/ch08/shannon/index.html*

A logical development of the undershot wheel is the overshot wheel. Gravity is responsible for the wheel going round in this case. Water falls from above on the buckets and turns them round. It requires greater civil engineering works for its installation; however, it pays back, as it is high efficient by full utilizing the water flow (Power in the Landscape 2008). The overshot water wheel is not affected by flood, however, it cannot be used for streams and rivers as the "head" of water should be at least as high as the diameter of the wheel (Boyle 2004, 159).

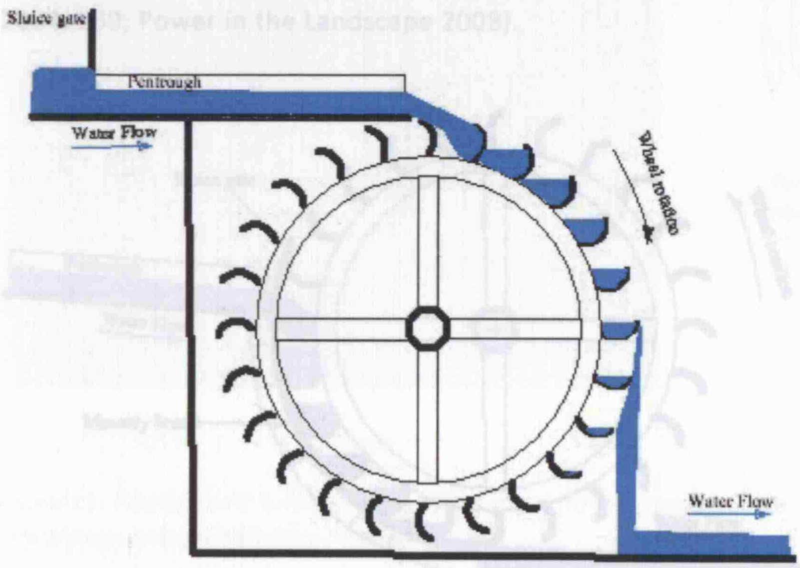



*Figure 12: An Overshot Water Wheel. SOURCE: http://www.powerinthelandscape.co.uk/water/water_wheels.html*

Characteristics of an overshot water wheel are shown below.

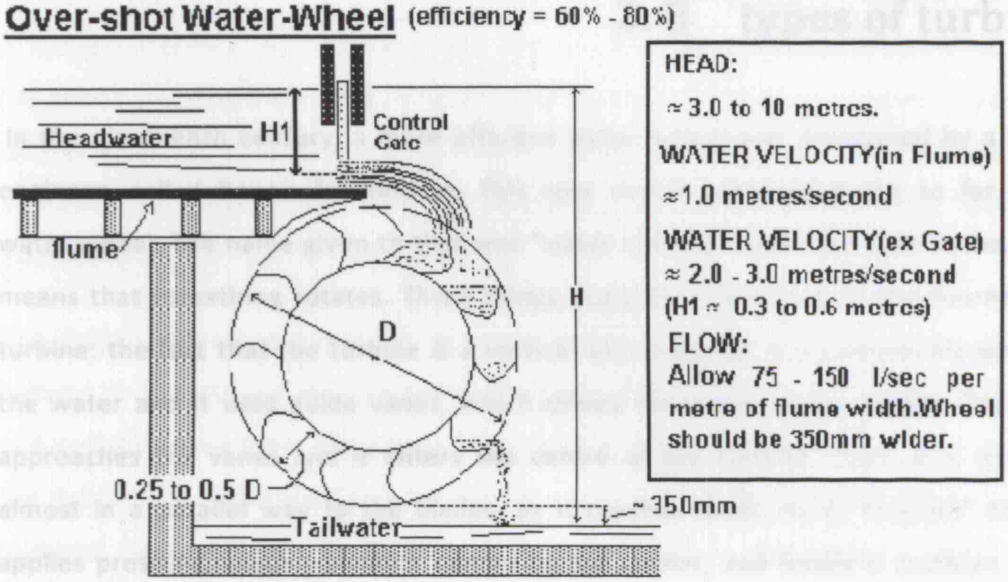



*Figure 13: Characteristics of an overshot water wheel. SOURCE: http://ipc6.permaculturewest.org/ch08/shannon/index.html*

For cases, where the head of water was inadequate for an overshot water wheel, the breastshot water wheel was used to pull away as much power from a stream as possible. The water is conducted between parallel breast walls and "feeds" the blades at about the level of the wheel axle. The advantage of this type of water wheel is that it does not suffer the flooding problems, and as for the civil engineering work, it would be less compared to the overshot water wheel and would depend on the site (Boyle 2004, 159; Power in the Landscape 2008).

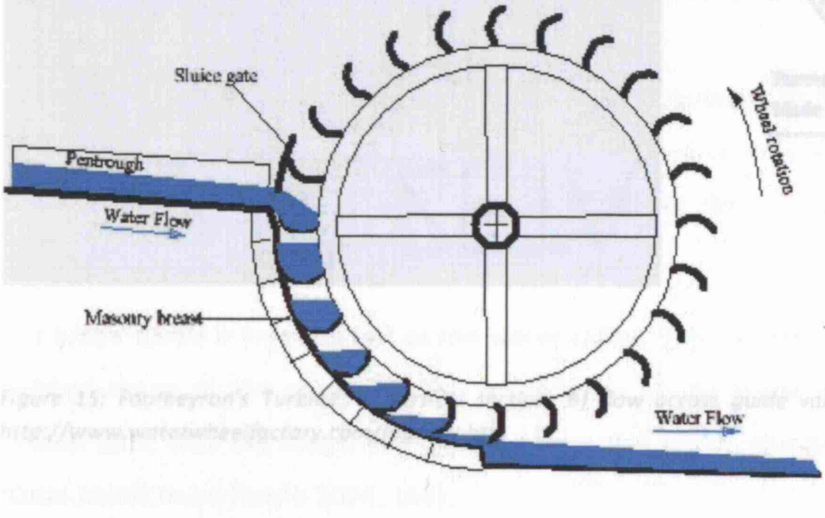



*Figure 14: A Breastshot Water Wheel. SOURCE: http://www.powerinthelandscape.co.uk/water/water_wheels.html*

## 2. 8 types of turbines

In the nineteenth century, a more efficient water wheel was discovered by a French engineer, called Benoit Fourneyron. This new device superseded the so far known water wheel. The name given to that was "water turbine", from the Latin *turbo*, which means that something rotates. Three things make the difference to the Fourneyron's turbine: the fact that the turbine is a vertical-axis machine; it is completely sunk into the water and it uses guide vanes, which drives the water to the blades. The water approaches the vanes and it enters the centre of the turbine. Then, it is travelling almost in a parallel way to the blades, as it reaches them. As it "touches" them, it applies pressure, which transmits energy to the runner, and finally it outflows (Boyle 2004, 160).

The Fourneyron's turbine had an efficiency of almost 80%, something that up till then, only the overshot wheels could have. Designed in 1832 and installed in 1837, this type of turbines, was the forerunner of the "modern" machines (Boyle 2004, 161).

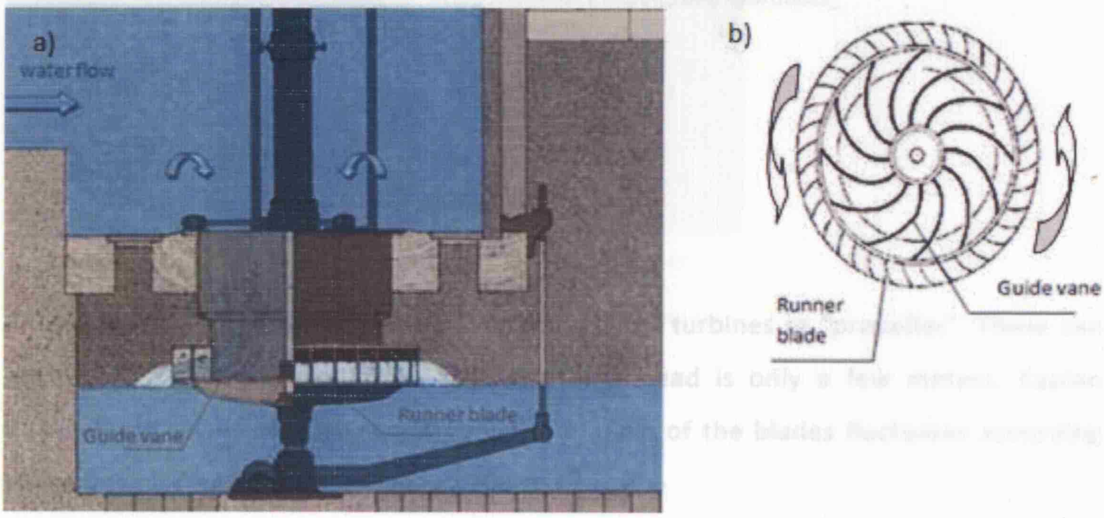



*Figure 15: Fourneyron's Turbine. a) vertical section; b) flow across guide vanes and runner. SOURCE: http://www.waterwheelfactory.com/fourney.htm*

There are two different basic types of turbine known as "reaction" and "impulse" turbines. "Reaction" turbines operate inside a pipe through which the water flows and it is the difference in pressure across the propeller that rotates the turbine. In the "impulse" turbines a high-speed jet of water strikes the specially-shaped cups on the wheel, which causes it to rotate and since the wheel is connected to a shaft, the kinetic energy is transferred from the wheel to the shaft (Centre for Alternative Technology Education).

The Francis turbine is a type of "reaction" turbine, which followed the Fourneyron's turbine. In Francis turbine, the water hits the turbine both axially (towards the axle) and radially (away from the centre). This type of turbine is commonly used today for the production of electrical power, and they operate in a head range of two to several hundred meters. For medium heads, between 30-500 m, the turbine output ranges from 10-800 MW (HITACHI 2008)!

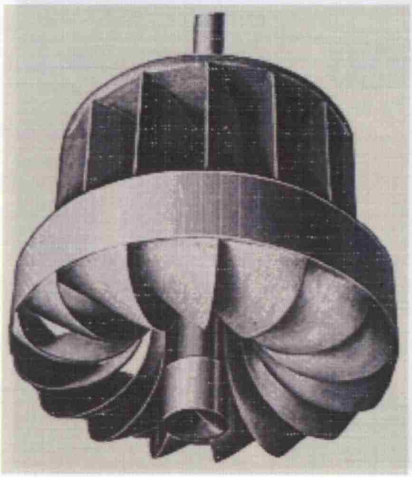


*Figure 16: Francis Turbine. SOURCE: http://members.tripod.com/hydrodocs_1/turbines.html*

Another type of "reaction" turbines is the axial-flow turbines or "propeller". These can be used for large volume flows and when the head is only a few meters. Kaplan turbines are axial-flow turbines, in which the angle of the blades fluctuates according to the power demand (Water Energy 2008).

The blade speed is twice as fast as the water speed. This can be easily explained by the twisted shape of the propeller. The outer parts of the blade move faster than the central part, thus the longer the distance from the axis is, the bigger the angle of the blade needs to be (Boyle 2004, 168).

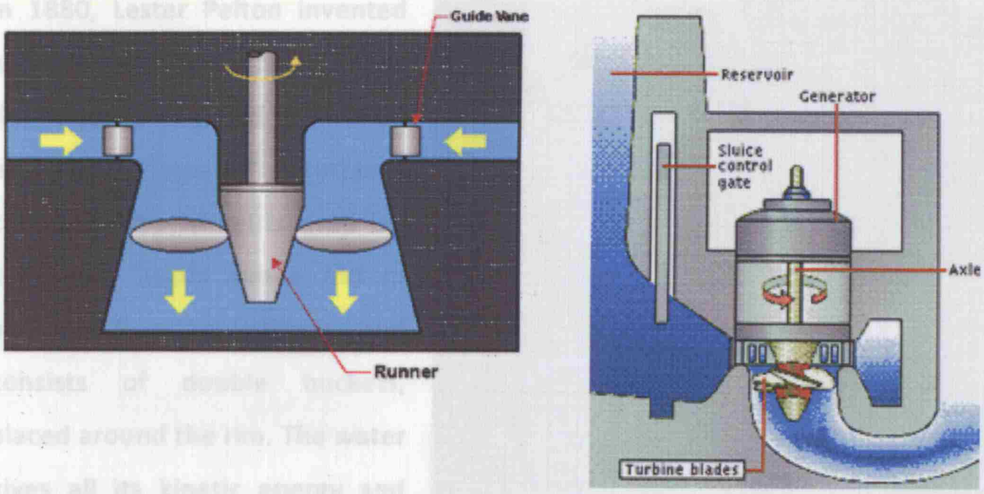



*Figure 18:* Left: *A "Propeller" Turbine. SOURCE:* http://re.emsd.gov.hk/english/other/hydroelectric/hyd_tech.html/
*Right: Kaplan Turbine. SOURCE: http://www.shomepower.com/dict/k/kaplan_turbine.htm*

*Figure 17: A propeller-type runner rated 28,000hp or horsepower, which is the equivalent of 20.880 kilowatts. SOURCE: http://www.worldofenergy.com.au/factsheet_water/07_fact_water_turbines.htm*

In 1880, Lester Pelton invented another type of turbine, called the Pelton wheel, and is enrolled in the "impulse" turbines category. This wheel is used for sites with heads above 250 m and low flow applications, and consists of double buckets, placed around the rim. The water gives all its kinetic energy and rotates the wheel, by being scattered between each pair of buckets. The wheel is fixed on a shaft and the motion of the turbine is transmitted from the shaft to a generator. Hence, mechanical energy is produced. The power varies in relation to the deflection of the jet away from the wheel (Boyle 2004, 169; The Encyclopedia of Alternative Energy and Sustainable Living 2008).

*Figure 19: The Pelton Wheel from the hydro power station in Walchensee, Germany. SOURCE: http://www.worldofenergy.com.au/factsheet_water/07_fact_water_turbines.html*

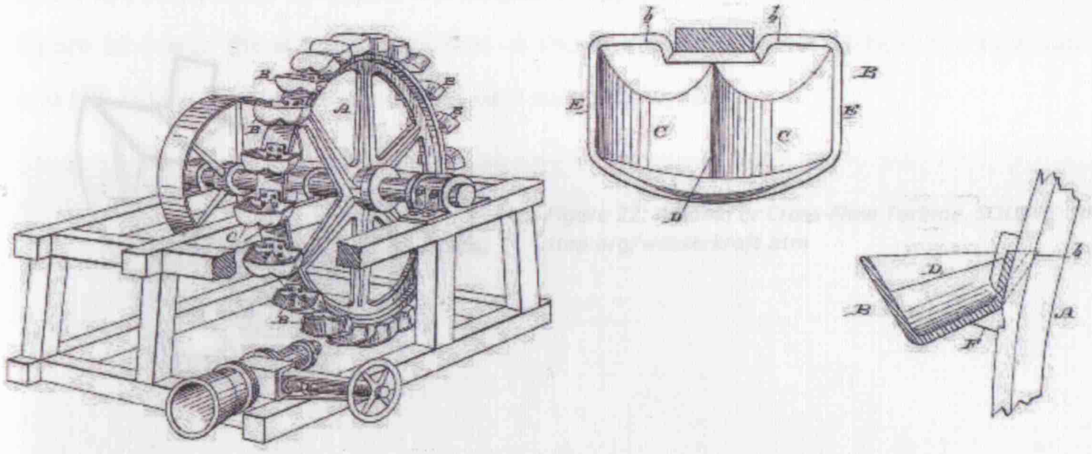


*Figure 20: The patent drawing of the Pelton Wheel. SOURCE: http://inventors.about.com/library/inventors/bl_lester_pelton.htm*

Some other types of "impulse' turbines are the Turgo turbine and the cross-flow turbine.

Turgo turbine developed in 1920s and is another version of Pelton wheel. It is located to medium head and high flow sites. Turgo turbine has shallower double buckets compared to the Pelton one, and water enters from one side and leaves from the other (Boyle 2004, 171).

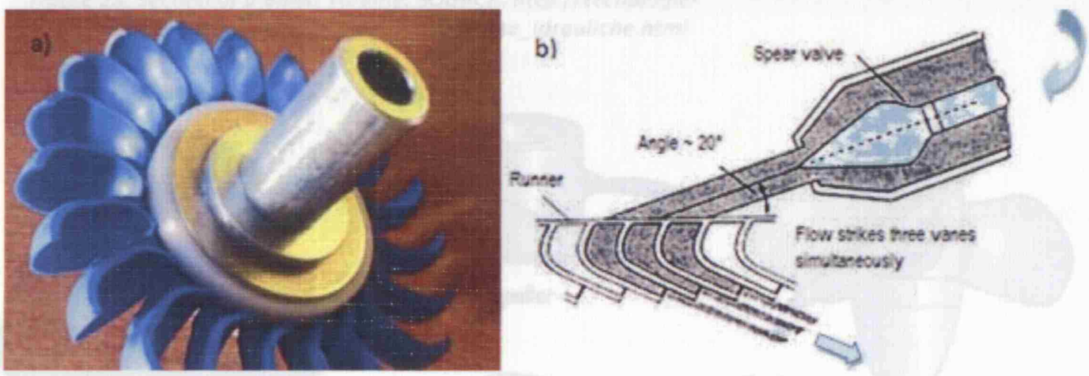



*Figure 21: A Turgo Turbine a) the runner b) water flow. SOURCE: http://tecnologie-energetiche.die.unipd.it/fr/idroelettrico/turbine_idrauliche.html*

The cross-flow turbine, or otherwise Mitchell-Banki, or Ossberger turbine is as already mentioned another type of impulse turbine. It can replace the Francis turbine when there is a significant flow but not enough head pressure to use a high head turbine. The water passes across the turbine blades and reaches the runner; then, it leaves from the opposite side (Boyle 2004, 171).

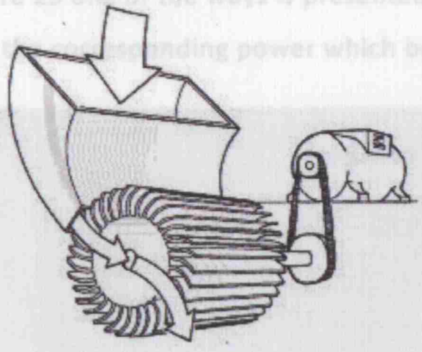


*Figure 22: A Banki or Cross-Flow Turbine. SOURCE: http://www.green-step.org/wasserkraft.htm*

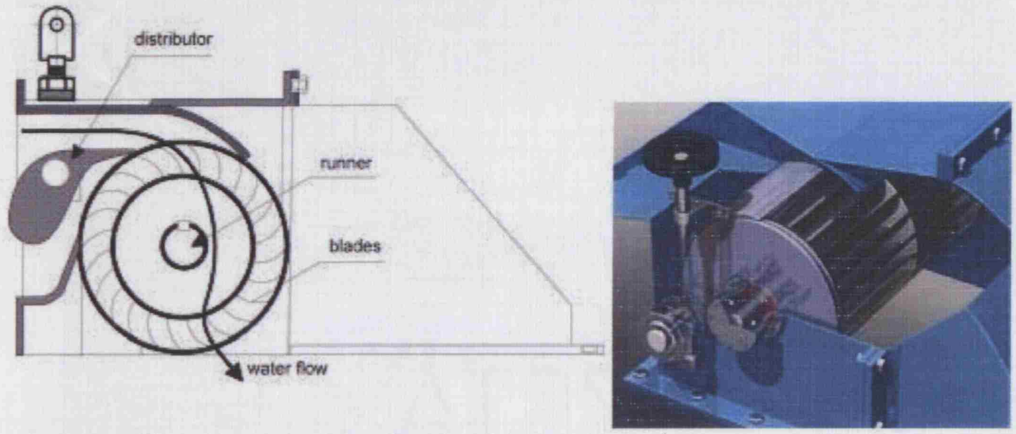



*Figure 23: Section of a Banki Turbine. SOURCE: http://tecnologie-energetiche.die.unipd.it/fr/idroelettrico/turbine_idrauliche.html*

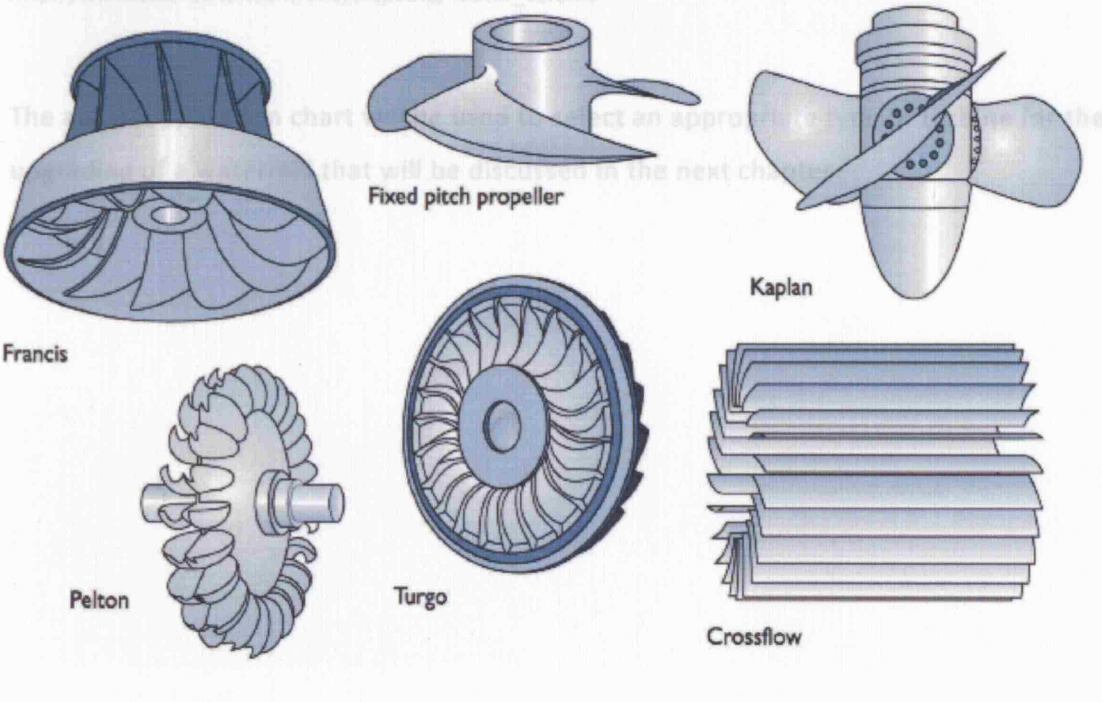



*Figure 24: All types of Turbine Runner. SOURCE: Boyle, 2004*

There are many ways to display the ranges of application of the different turbines. In Figure 25 one of the ways is presented. It shows the head of installation, the flow rates and the corresponding power which best suit each type.

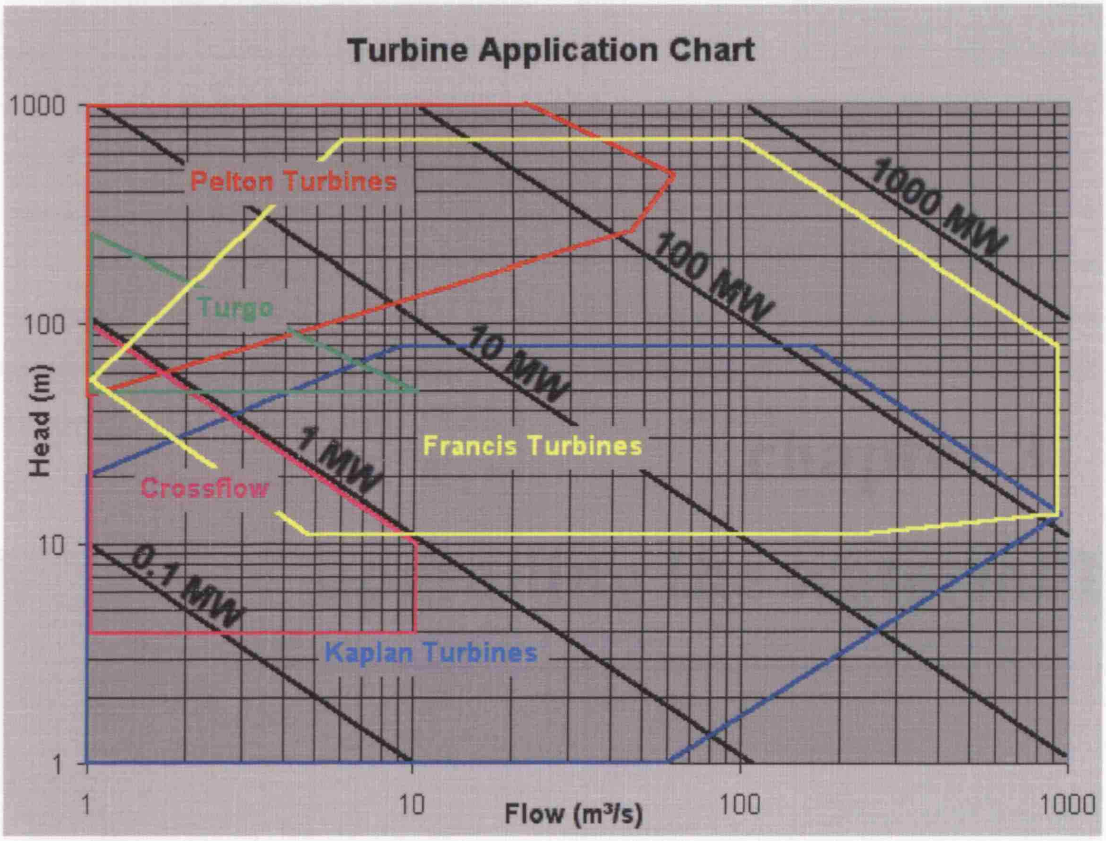



*Figure 25: Water Turbine application chart. SOURCE: http://www.biocrawler.com/encyclopedia/Water_turbine*

The above application chart will be used to select an appropriate type of turbine for the upgrading of a watermill that will be discussed in the next chapter.

# chapter 3

# upgrading the watermill

# 3.1 introduction

In the following chapter an old Hampshire watermill, the Whitchurch Silk Mill, was assumed to be located in two different rivers, with different average flow rates, in the southern part of Britain. The rivers that have been chosen are Dever River at Bransbury and River Itchen at Highbridge and Allbrook. The watermill will be used for residential purposes and a study has to be conducted in order for the naturally powered building to be energy efficient. For this reason the wheel of the mill will be replaced by a turbine. A hydraulic study follows, in which the power, with which the turbine will supply the mill, will be calculated for both the maximum and minimum flow of each of the rivers.

**BOX 1 History of the Hampshire Mill**

Located in the Upper Test Valley Floor the Whitchurch Silk Mill was constructed in 1800 and was originally used as a fulling mill. After 16 years, in 1816, William Maddick became the director of the mill, and by 1830s the mill was known for its silk weave. After Maddick, the mill passed into the ownership of the Chappell family. The weaving by that period was done on floor looms powered by the weaver (Whitchurch Silk Mill 2008).

In 1889 the mill was purchased by the Hide family. It was then, when the production was modernized. The Hide family introduced powered looms, winding frames and a warping mill run by the waterwheel, thus a larger waterwheel was installed to provide the power, which was required. However, this did not last for long, as after the Second World War the water power was replaced by electric motors installed on the mill's machines (Whitchurch Silk Mill 2008).

Stephen Walter and Company followed the Hide family, and after him Ede and Ravenscroft became its owners. Some financial problems led to the purchase of the mill by the Hampshire Buildings Preservation Trust in 1985 and in 1990 the mill was leased to the Whitchurch Silk Mill Trust and since then the weaving continues yup to nowadays, using the historic machinery for producing silk (Whitchurch Silk Mill 2008).

## 3. 2 data collection of the study area

Two rivers are going to be examined and compared as to whether they can provide an adequate power to fulfill the needs of the watermill as a residential building. River Dever at Bransbury and River Itchen at Highbridge and Allbrook are on the south part of Britain. The reason why these two rivers have been selected is that they have different mean flow rates, while the difference in the average annual rainfall is not of severe importance.

Data collection for the national Flood Event Archive, maintained by the Centre for Ecology & Hydrology (formerly the Institute of Hydrology) (Centre for Ecology and Hydrology 2008) shows that the mean flow in River Dever is $1.23\,m^3/s$. The maximum flow rate is $2.475\,m^3/s$ while the minimum flow rate is $0.298\,m^3/s$ and the average annual rainfall is $780\ mm$ gauged from 1999 to 2006.

According to some daily flows being gauged from 2000 to 2004 (Centre for Ecology and Hydrology 2008), the sample hydrograph and flow duration curve are presented in the following Figure.

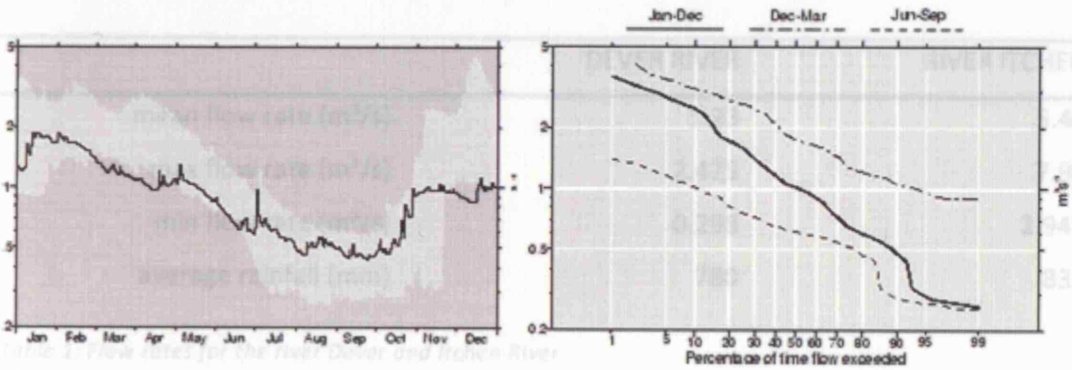



*Figure 26: Left: Sample Hydrograph of Gauged Daily Flows. Max and min daily mean flows from 2000 to 2004. Right: Flow Duration Curve for Gauged Daily Flows.*
*SOURCE: http://www.nwl.ac.uk/ih/nrfa/station_summaries/042/027.html*

For River Itchen the data collected according to Centre for Ecology & Hydrology is that the mean flow is $5.40\ m^3/s$, with a maximum and minimum flow rate $7.98\ m^3/s$ and $2.947\ m^3/s$ respectively. The average annual rainfall is $833\ mm$. The Gauged Daily Flows (gdf) are from 1958 to 2008, while the Monthly Catchment Rainfall (rnf) is made from 1959 to 2006.

According to daily flows gauged from 1958 to 2008 (Centre for Ecology and Hydrology 2008) the sample hydrograph and flow duration curve are presented in below.

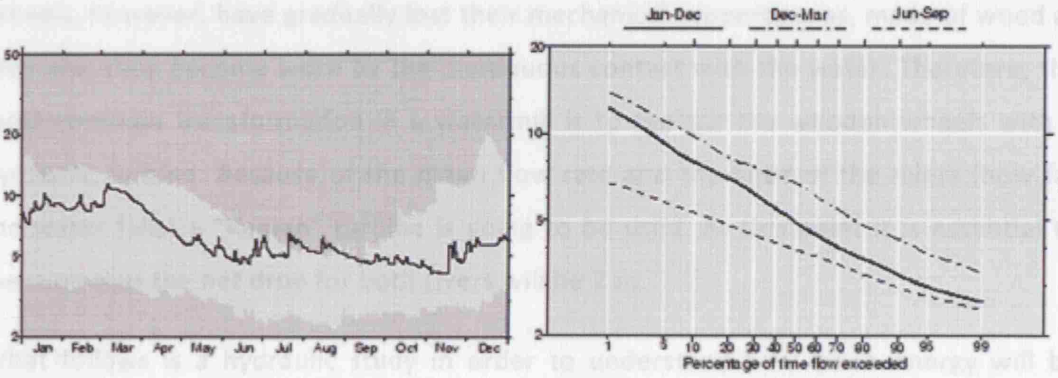



*Figure 27: Left: Sample Hydrograph of Gauged Daily Flows. Max and min daily mean flows from 1958 to 2008. Right: Flow Duration Curve for Gauged Daily Flows. SOURCE: http://www.nwl.ac.uk/ih/nrfa/station_summaries/042/027.html*

| | DEVER RIVER | RIVER ITCHEN |
|---|---|---|
| mean flow rate ($m^3/s$) | 1.23 | 5.40 |
| max flow rate ($m^3/s$) | 2.475 | 7.98 |
| min flow rate ($m^3/s$) | 0.298 | 2.947 |
| average rainfall (mm) | 780 | 833 |

*Table 1: Flow rates for the river Dever and Itchen River*

## 3. 3 the turbine

All watermills have the input and output of the water, which moves the wheel. The river provides water to the mill, transforming the water's potential energy into kinetic energy, which moves the blades of the wheel, which in turn causes the milling stones to move. The level of water in any river is controlled by sluice gates. When the river level is low, the gates are controlled in such a way to provide more flow to the water wheel. When the river level is too high, the gates open to allow the water to pass downstream.

Wheels, however, have gradually lost their mechanical properties, as, made of wood as they are, they become worn by the continuous contact with the water. Therefore, the most common transformation in a watermill is to replace the wooden wheels with a hydraulic turbine. Because of the mean flow rate and the head of the rivers (how far the water falls) a "Kaplan" turbine is going to be used. At this point it is essential to mention that the net drop for both rivers will be 2 m.

What follows is a hydraulic study in order to understand how much energy will be available to the watermill by the use of the turbine.

**BOX 2 The Wheel of the Whitchurch Silk Mill**

The Whitchurch Silk Mill has an undershot water wheel that is used to provide power to 16 looms that weave silk cloth. The water passes underneath the wheel and pushes the wooden floats round, thus the water wheel turns. This motion is then transferred from it using gears and axles. The power generated is finally directed to the machinery by a drive belt, being turned by an overhead shaft.

*Figure 28: Left: The water wheel rotates and transfers the motion using gears and axles. Right: The overhead shaft powered by the water wheel. SOURCE: http://whitchurchsilkmill.org.uk*

### 3.3.1 hydraulic study

The flow of water and the height of the water drop are both essential for the calculations as far as the turbine is concerned. Calculations will be conducted for both of the rivers for their maximum and minimum flow rates and for a net drop of 2 m.

Taking a cross sectional area of 10 m² (5 m x 2 m) of the river, it is assumed that the water flow that will come through the turbine is 10% of the flow of the river. Hence, the flows that will be used by the turbine for each of the rivers are shown in the table below.

| | DEVER RIVER | RIVER ITCHEN |
|---|---|---|
| max flow rate ($m^3/s$) | 0.2475 | 0.798 |
| min flow rate ($m^3/s$) | 0.0298 | 0.2947 |

*Table 2: Water flows used by the Kaplan turbine*

To calculate the power supplied by the falling water to the turbine, Equation (2) from paragraph 2.2, Chapter 2 is going to be used, according to which:

$$P = 1000 \times Q \times g \times H(W) \qquad (2)$$

where,

$Q$: the flow of the river used by the turbine (10% of the river flow) in $m^3/\sec$

$g = 9.81 m/s^2$ : the gravitational acceleration

$H$ :the net drop, being $2m$

### RIVER DEVER

maximum flow rate

$$Q = 0.2475\, m^3/\sec$$

$$P = 1000 \times 0.2475 \times 9.81 \times 2 \Rightarrow P = 4855.95W = 4.856\, kW$$

minimum flow rate

$$Q = 0.0298\, m^3/\sec$$

$$P = 1000 \times 0.0298 \times 9.81 \times 2 \Rightarrow P = 584.676W = 0.59\, kW$$

### ITCHEN RIVER

For Itchen River the same calculations are going to be made. It is though expected a greater power of the turbine, as the mean flow rate of the river is higher than that from River Dever.

maximum flow rate

$$Q = 0.798\, m^3/\sec$$

$$P = 1000 \times 0.798 \times 9.81 \times 2 \Rightarrow P = 15656.76W = 15.657\, kW$$

minimum flow rate

$$Q = 0.2947\, m^3/\sec$$

$$P = 1000 \times 0.2947 \times 9.81 \times 2 \Rightarrow P = 5782.014W = 5.782\, kW$$

### 3.3.2 analysis of the results

The energy calculated in the previous paragraph, is the energy available from water. The potential energy due to the head of water is converted into kinetic energy in the form of fast-moving water passing through the turbines. This is then converted into rotational kinetic energy by the blades of the turbine. Finally, it is the spinning of the turbine that drives the generator to produce electricity (Boyle 2004, 203). Hence, the system that produces electricity is never 100 per cent efficient. The efficiency expected from these systems is 50-60 per cent (Centre for Alternative Technology Education).

Assuming that the efficiency of Kaplan turbine placed in the river is 50%, during winter, when flows are at its maximum value, the available power given to fulfill the needs of the building is 21269 kWh and 68577 kWh for River Dever and Itchen River respectively. During summer period flows become lower thus the available energy decrease. The values of energy are 2561 kWh and 25325 kWh for Dever and Itchen River respectively (Table 3).

| | water flow ($m^3$/sec) | head of water (m) | available power from water (kW) | efficiency of the turbine (%) | available power from turbine (kW) | available power from turbine (kWh) |
|---|---|---|---|---|---|---|
| River Dever | 0,2475 | 2 | 4,856 | 50 | 2,428 | 21269 |
| | 0,0298 | 2 | 0,585 | 50 | 0,292 | 2561 |
| Itchen River | 0,7980 | 2 | 15,657 | 50 | 7,828 | 68577 |
| | 0,2947 | 2 | 5,782 | 50 | 2,891 | 25325 |

*Table 3: Available power from the turbine*

In order to figure out what exact percentage of the house's energy needs would be covered by the turbine, it is essential that we calculate the demand of the energy that the building will require. In the next chapter the house is modeled in a building simulation computer program in order to estimate this demand.

# chapter 4
# modeling the watermill energy demand

## 4.1 building description

The mill that will be refurbished is Whitchurch Silk Mill in Whitchurch, Hampshire. It is originally sited adjacent to Test River, which is the power source for its function. The mill is a three-storey building with long front façade and external walls punctuated at regular intervals with large windows. Wrought iron members in regular bays form an internal frame, which supports the floors. It has large interior spaces as well as adequate external space around the building, for access.

In terms of the dissertation, the mill will be placed adjacent to River Dever and Itchen River in such a way that its main façade will face the rivers. This watermill will be upgraded to fulfill residential needs. Two cases related to the design of the mill will be examined. In the first case, the building will consist of two family-flats. The second case is that the whole building will be divided into two different flats in each floor to accommodate 6 couples.

## case No 1: 2 flats for 2 four-member families

The three storey building is divided into two similar flats to accommodate two different four-member families. Each flat has an area of 145.8 $m^2$, 48.6 $m^2$ in each floor. The orientation of the building is South-East. At the first floor the dining and living room, where the family gather most time of the day are designed to be in the front, so as to face the river, while the kitchen, WC and laundry room are located at the back side (North-West). The stairway, leading to the bedrooms of the house at the second and third floor as well as the study room is at the back of the apartment. The three bedrooms and study room are designed to face the main façade of the building.

There are no windows neither in the North-East nor in the South-West side, because the mill consists of two adjoining buildings, the long mill proper and the taller, which used to be the mill owner's house.

The original image of the watermill and the plans after its renovation are presented below.

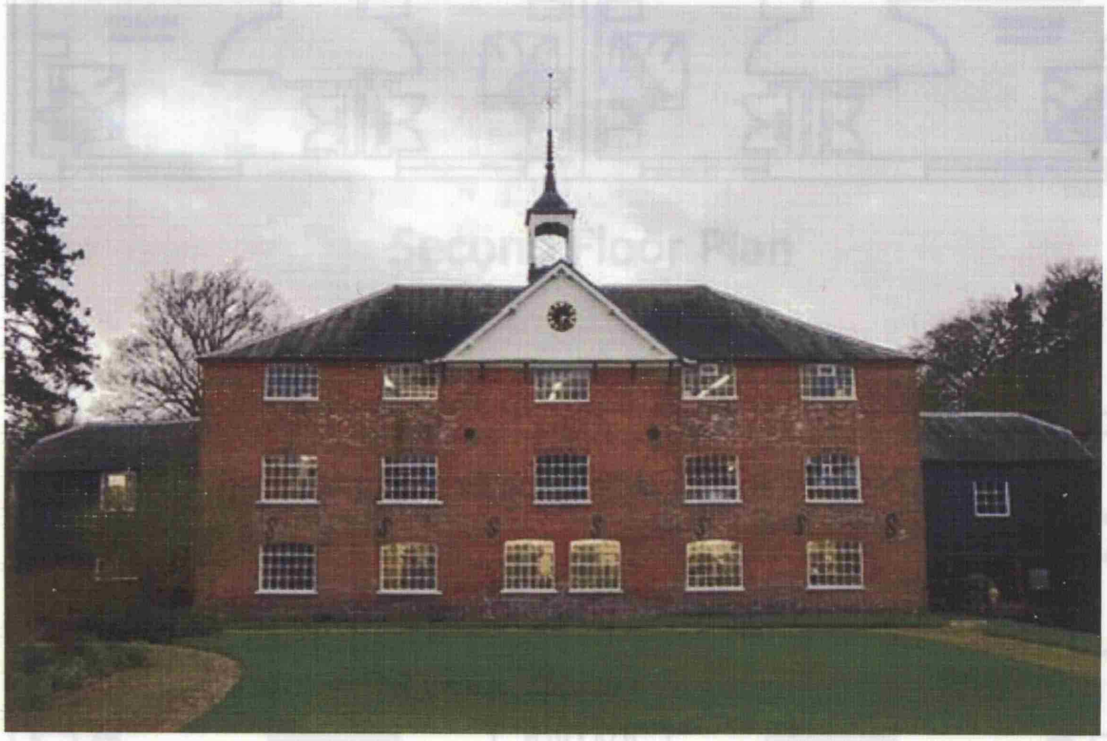
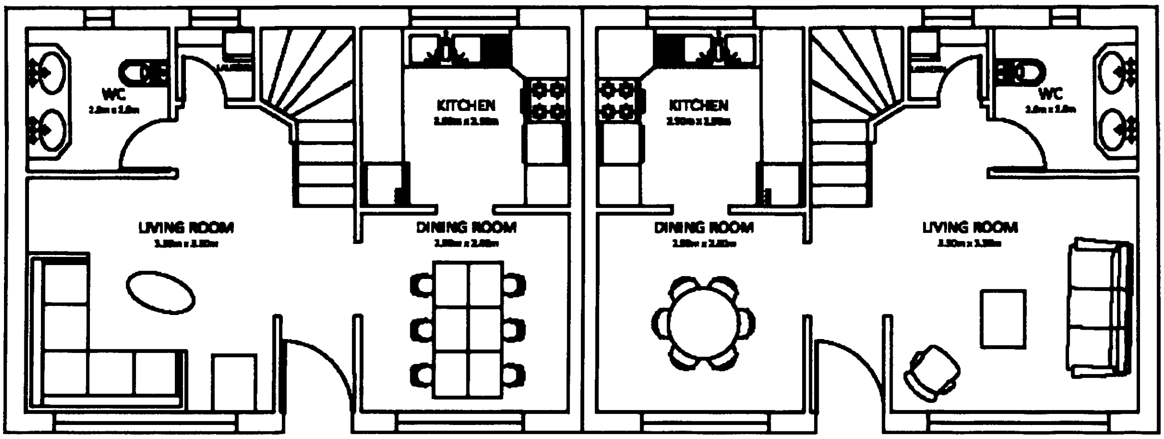
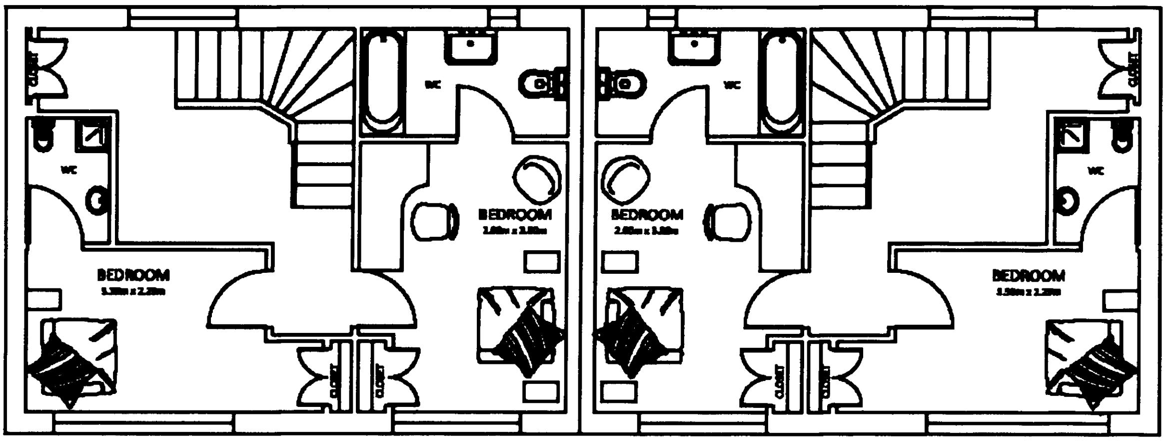


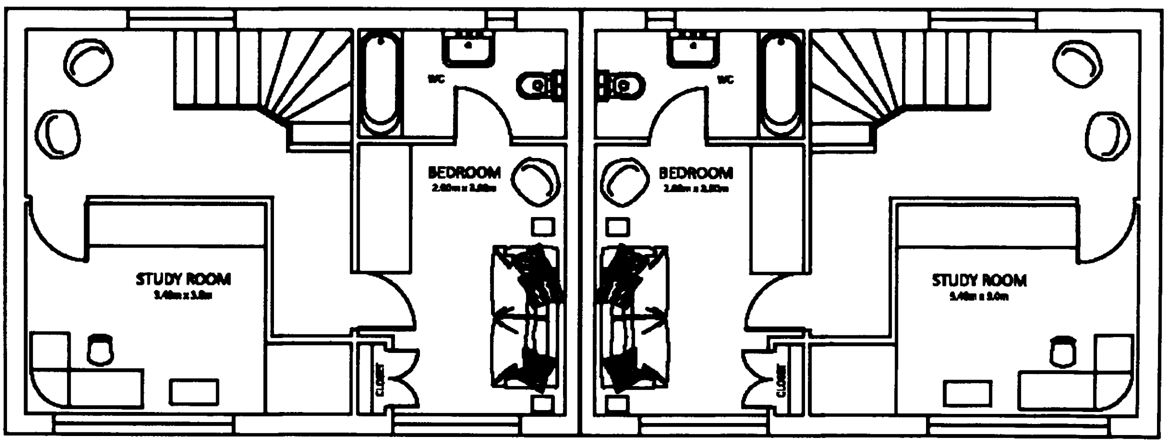
*Figure 29: The Whitchurch Silk Mill. SOURCE: http://whitchurchsilkmill.org.uk/schools/schools.html*




First Floor Plan




Second Floor Plan



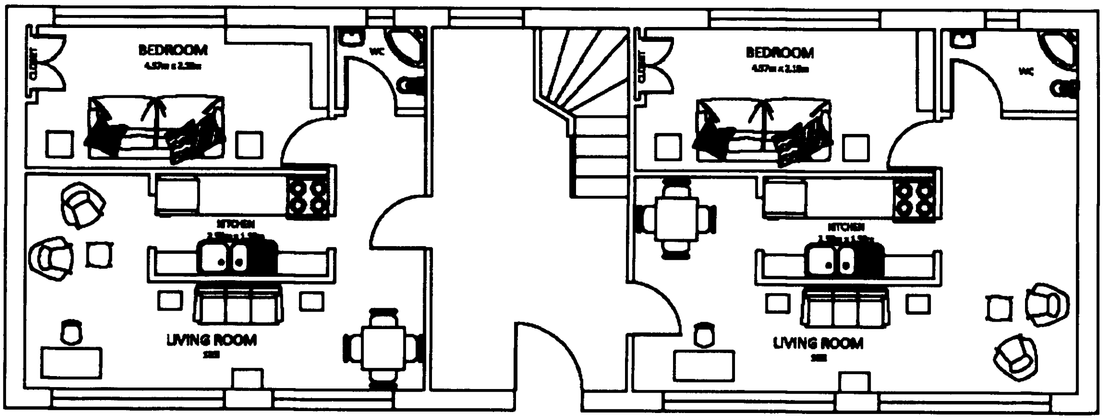

Third Floor Plan

### case No 2: 6 flats for 6 couples

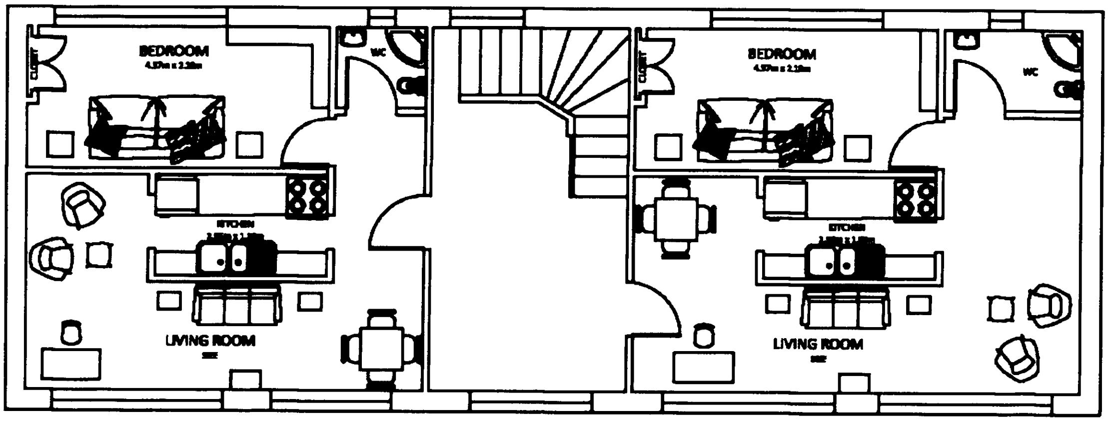
At this case, the original watermill is going to accommodate six couples living in six flats; hence two flats are constructed in each floor. The left apartment of every floor is of 38 $m^2$, while the right one has an area of 42 $m^2$. In both flats the living room faces the South-East facade (main facade) and the bedrooms are designed to be North-West orientated (back side of the structure).

As it is in case No 1, in this case there are windows neither in the North-East nor in the South-West side, due to the existence of two adjacent buildings.

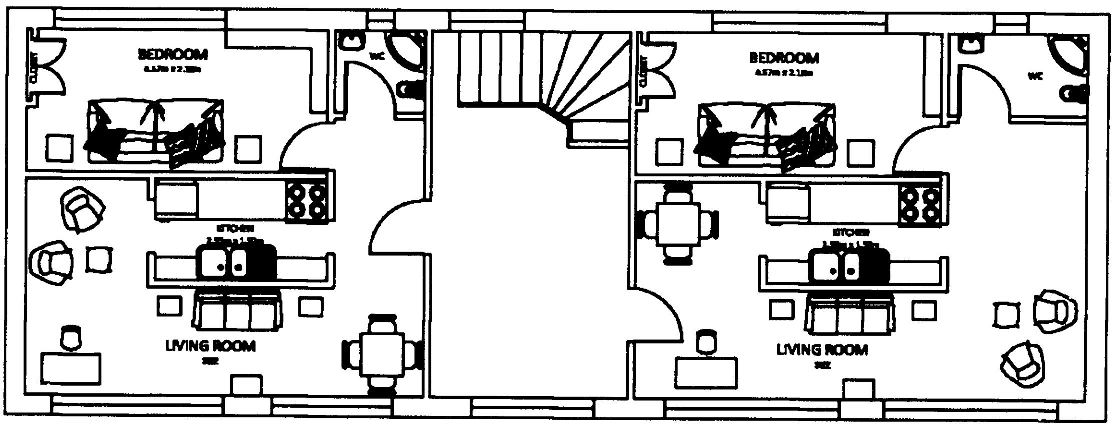
The plans of flats are shown below.




First Floor Plan




Second Floor Plan




Third Floor Plan

The construction materials for both of the cases will be the same, as our aim is to calculate the energy demand of the mill, as a residential building, according to its occupancy and different arrangement of its internal space, and not according to different structural elements. Description and analysis of the construction materials will be conducted in the following paragraph, in which the modeling of the house is been simulated with a dynamic building simulation program, TAS from EDSL (EDSL 2007).

## 4.2 modeling the building

The building was modeled in TAS simulation program.

In the first case, in which the mill accommodates two large three-storey apartments for two four-member families, it is decided to separate the building into two different zones, represented by the pink and blue colour. The reason for doing this is because after the simulation of the edifice, each house will have its own amount of energy demand. Our main interest is to figure out if the turbine could cover this demand for each of the two apartments, both in winter (maximum flow rate) and during summer period (minimum flow rate).

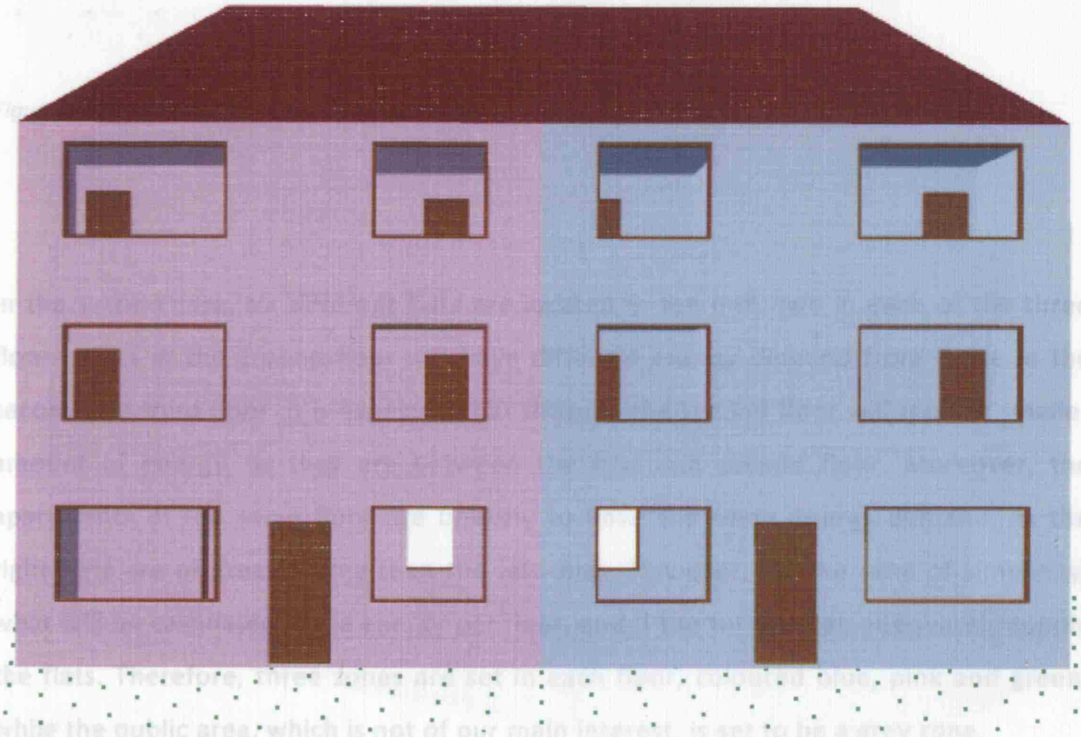


*Figure 30: South-East/main façade of the mill.*

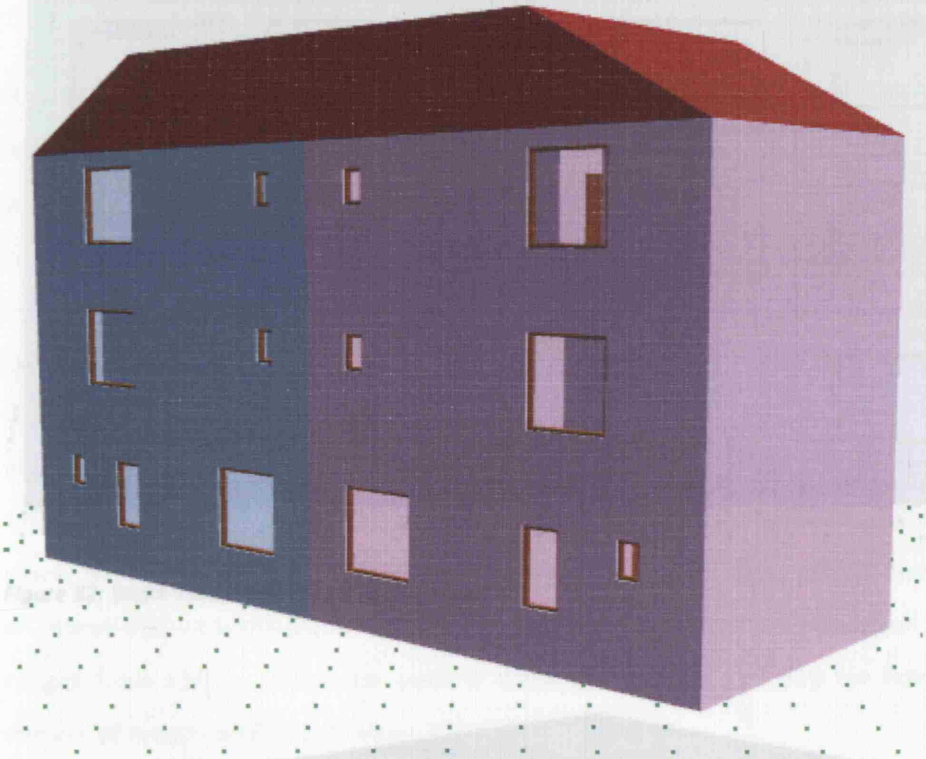


*Figure 31: North-West/back façade of the mill.*

In the second case, six different flats are located in the mill, two in each of the three floors. Flats in the ground floor will have different energy demand from those in the second and third floor. It is expected that those in the second floor will require smaller amount of energy, as they are between the first and second floor. Moreover, the apartments of the same floor are unlikely to have the same energy demand, as the right flats are of greater area than the left ones. However, for the sake of simplicity, what will be calculated is the energy per floor, and if the turbine can adequately supply the flats. Therefore, three zones are set in each floor, coloured blue, pink and green, while the public area, which is not of our main interest, is set to be a grey zone.

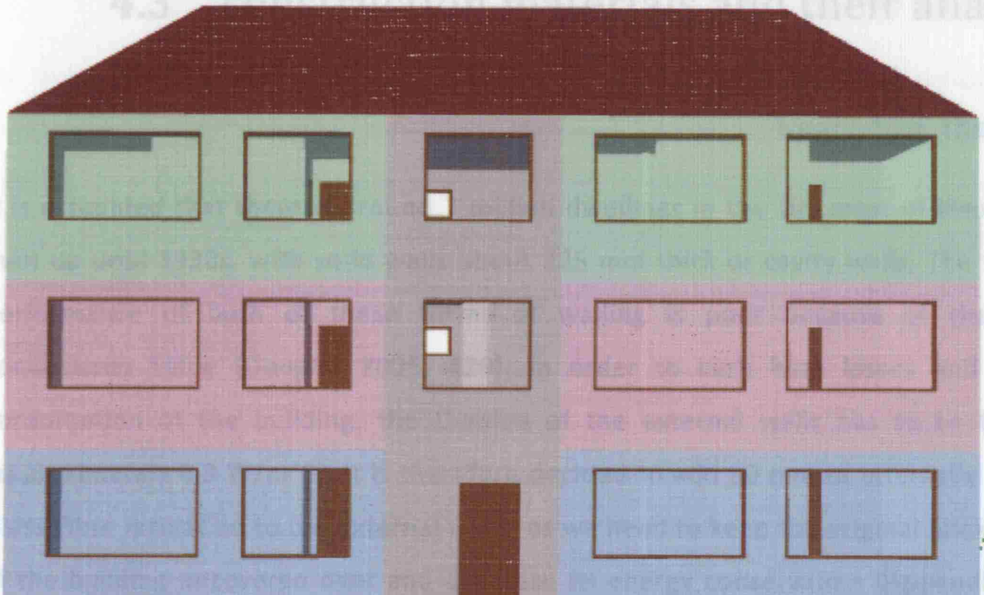


*Figure 32: South-East/main façade of the mill.*

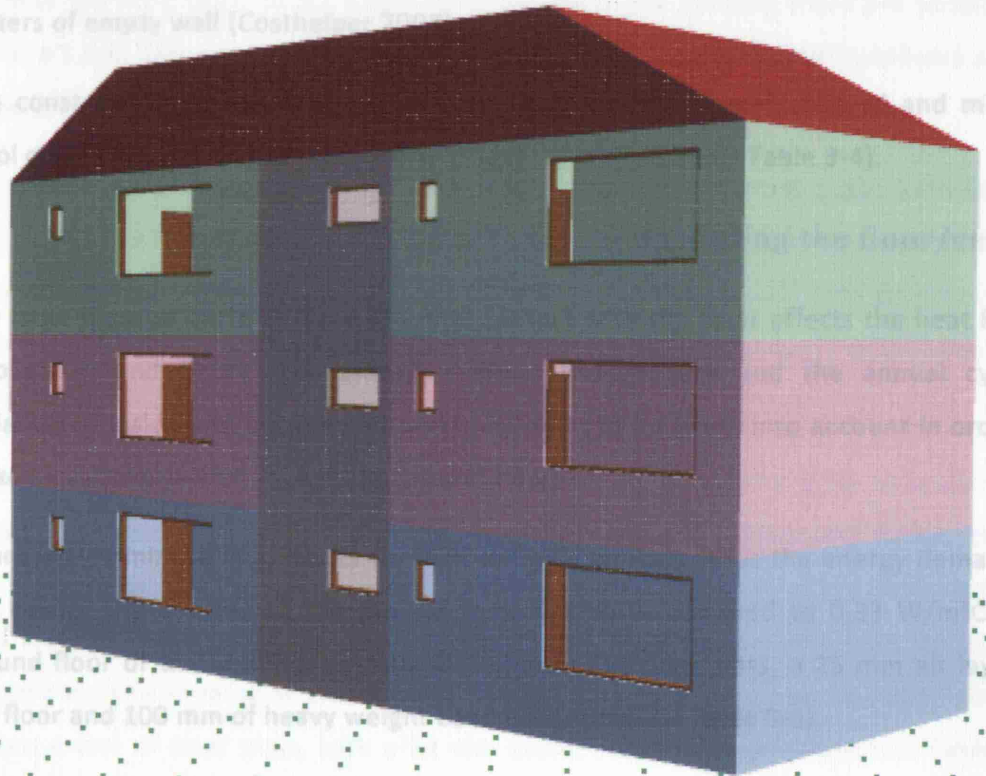


*Figure 33: North-West/back façade of the mill*

## 4.3 construction materials and their analysis

### upgrading the walls

It is estimated that there is around 7 million dwellings in the UK, most of them being built up until 1930s, with solid walls about 225 mm thick or cavity walls. The thermal performance of both of these forms of walling is poor because of their high conductivity value (Douglas 2005, 429). In order to curb heat losses and energy consumption of the building, the U-value of the external walls has to be lowered (approximately 0.3 W/m$^2$C). It is therefore decided to add 80 mm of internally applied Glass Fibre insulation to the external walls, as we need to keep the original brick-façade of the building uncovered over and decrease its energy conservation (Appendix Table 1-2). Moreover, this method precludes the use of the building's thermal mass as a heat store; hence it encourages thermal stresses in the outer skin, which increases the risk of interstitial condensation within the element. The cost of insulation into the wall ranges from £10.0 - £19.0 per square meter, or £1,000 - £1,900 for filling 100 square meters of empty wall (Costhelper 2008).

The construction elements of the internal walls consist of plasterboard and mineral wool quilt 50 mm thick and its U-value is 0.62 W/m$^2$ (Appendix Table 3-4).

### upgrading the floor/ceiling

The large mass of earth being in thermal contact with the floor affects the heat losses through ground floors. The annual average temperature and the annual cyclical variation of inside and outside temperatures need to be taken into account in order to make an appropriate change in the ground floor.

In order to minimize heat losses through the ground floor, thus the energy demand of the house, the U-value of the ground floor has to be lowered to 0.33 W/m$^2$C. The ground floor of the building consists of 100mm of cellular glass, a 25 mm air layer in the floor and 100 mm of heavy weight concrete (Appendix Table 5-6).

Intermediate floors of the building are plywood suspended floors with a U-value of 2.2 W/m$^2$C. (Appendix Table 7-8).

### upgrading the roof

In order to improve the energy efficiency of the roof, 150 mm of mineral fibre insulation has been placed in the floor achieving a U-value of 0.24 $W/m^2C$. This vapour control layer is placed on the warm side of the construction to avoid any interstitial condensation problems in the roof system. The middle part of the roof remained flat and the left and right sides are left pitched so as not to change the roof's basic profile. (Appendix Table 9-10).

### window replacement

The existing openings are disturbed to accommodate new windows and doors. Presented openings are slightly widened. More specific, in case No 1 two entrance doors (each for every apartment) of 0.96 m x 2.2 m have replaced the space between the original submarginal windows. The main façade of each of the apartments consists of two windows of 2.5 m x 1.5 m and 1.7 m x 1.5 m, which corresponds to the living and dining room, as well as to the bedrooms of second and third floor and to the study room in the third floor. In the North-West façade of the building there are windows of 1.5 m x 1.5 m corresponding to the kitchen area and staircase. All WC windows are set to be 0.4mx0.6m and the window of the laundry room is 0.7 m x 1.3 m.

In case No 2 an entrance door of 1.0 m x 2.2 m has replaced the space between the existing windows being in the middle. In all left-side flats, both in the main and back façade there are windows of 2.5 m x 1.5 m and the WC window is 0.4 m x 0.6 m. In the right-side flats the windows' dimensions are also 2.5 m x 1.5 m and the WC window is 0.5 m x 0.6 m.

The thermal transmittance of windows is made up of the centre-pane *U*-value of the glazing, the frame or sash and the interaction between the glazing and frame, include the effect of the glazing spacer bars in multiple glazing. The pane of the mill's windows was assumed to be original single-glazed. These windows are replaced by double-glazed pane of a U-value of 2.86 $W/m^2C$, in order to reduce heat loss. The pane consists of two 4 mm of clear glass, with a 12 mm cavity between them (Appendix Table 11). The frame of windows and doors is softwood aluminium spacer of 50 mm with a U-value of 2.0 $W/m^2C$ (Appendix Table 12).

## 4.4 internal conditions and aperture types

The internal conditions have set to be the same for all flats. According to temperatures of South-East England, winter is assumed to be from 1 January until 5 June and from 7 September until 31 December (days 1-155 and 249-365), while summer is from 6 June until 6 September (days 156-248).

During winter a thermostat has been set to provide heat to the apartments. In all cases the heating is assumed to provide a resultant temperature of 20°C to 23°C during heating hours, being 18:00-9:00 during weekdays and all day long during weekends. The roof and public areas are considered to be unoccupied and unheated. During summer the flats are naturally ventilated with windows being opened in the rooms if the zone temperature exceeds 21°C and shut if it is over 26°C.

Internal heat gains are based on CIBSE Thermal Comfort (CIBSE Thermal Comfort, 18-20). With occupancy 4 persons in the first case (four-member family flat) and 2 persons in the second (flat for couple), lighting and equipment set to be on in late evenings until early mornings with the exact occupancy schedules as shown in Table 5 during weekdays and during weekends they set to be on all day long (Table 6).

Ventilation is required within the dwellings to provide a comfortable and healthy environment for the residents. The air infiltration rate is set to be 0,5 air change per hour, as it is a value recommended by SAP2001 for naturally ventilated airtight dwellings. The past recommended value for ventilation rate was 1 air change per hour and is set in the roof.

| | | |
|---|---|---|
| winter | 1 January-5 June and 7 September-31 December | start heating if the zone temperature < 20°C and stop > 23°C |
| summer | 6 June-6 September | no heating: windows open in a room if the zone temperature > 21°C and shut > 26°C |

*Table 4: Occupancy schedule information*

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| all flats | x | x | x | x | x | x | x | x | x | | | | | | | | | x | x | x | x | x | x |

*Table 5: Occupancy schedule by hour of day for weekdays*

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| all flats | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x |

*Table 6: Occupancy schedule by hour of day for weekends*

# chapter 5

# discussion

### case No 1: 2 flats for 2 four-member families

The resulting energy consumption profiles for the "two four-member-family apartments" case are displayed in Figure 34. According to the depicted diagram, a flat of 146 m² in South-East England, with the internal conditions mentioned in the previous paragraph, uses almost 3500 kWh per year for space heating, which is about 18% of the total energy consumption of the flat, while for water heating purposes uses 2500 kWh per year, counting for 14% of its total energy consumption (Figure 35).

A percentage of 34% of the annual energy consumption of each of the flats is responsible for lighting. Taking as granted that the lighting gains in the house are 8 W/m², the energy that the flat needs to be lightened is up to 4700 kWh during winter, while in the summer, where the daylight factor available in the house is higher, it is only 1600 kWh.

Electronics, such as VCR/DVD player, stereo system, television, desktop computers and laptops, computer printers, microwave oven, refrigeration, washer and dryer and many other appliances used in the kitchen or by the occupants at certain times, e.g. vacuum cleaner, hair-dryer, etc., use also 34% of the energy that the house consumes annually. The equipment gains set were 8 W/m², as already mentioned in the previous paragraph, because there will be many times within a whole year that most of the devices will be used at the same time by all four occupants of the apartment.

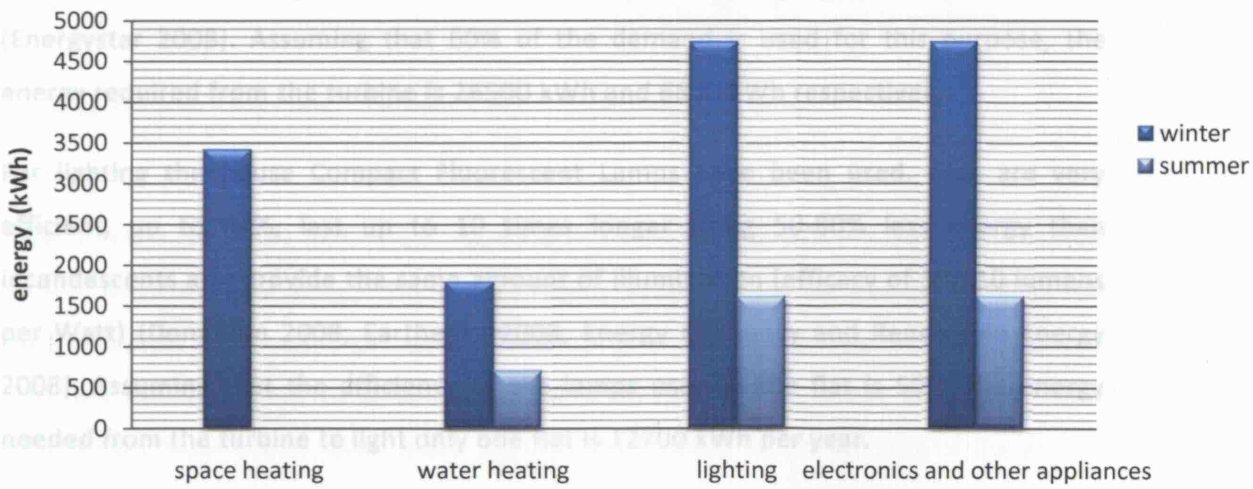



*Figure 34: Energy consumed by a four-member-family apartment in winter and summer season*

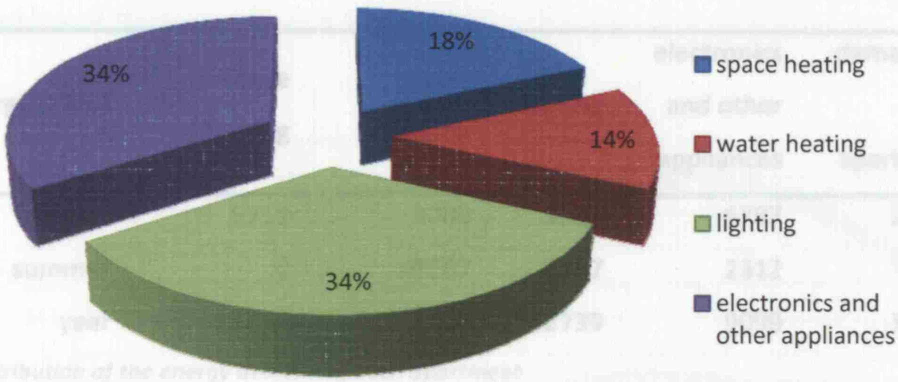



*Figure 35: Annual energy consumption of the apartment for different purposes*

Despite the fact that TAS gives the energy consumption of each flat, what is of great importance to us is the energy needed from the flat, in order to be used. The consumption has to deal with the efficiency of space and water heating systems, lighting and all other appliances. Calculating the efficiency of each of the aforementioned systems, the energy demand of the each flat, involving the building itself, will be known.

The efficiency of a high-efficient space and water heating system can be 45-60% (Energystar 2008). Assuming that 60% of the demand is used for this purpose, the energy required from the turbine is 26500 kWh and 6800 kWh respectively.

For lighting the house Compact Fluorescent Lamps have been used. CFLs are very efficient, up to 62%, last up to 10 times longer using 50-80% less energy than incandescents and provide the same amount of illumination (efficacy of 30-110 lumens per Watt) (Dominion 2008; Eartheasy 2008; Energy Efficiency and Renewable Energy 2008). Assuming that the efficiency of the lamps used in the flat is 50%, the energy needed from the turbine to light only one flat is 12700 kWh per year.

The average efficiency of the electronics and other appliances that a household uses is assumed to be 70%. Therefore, the annual energy that the apartment of 146 $m^2$ requires for the devices is almost 9100 kWh.

The energy requirement to fulfill all the needs of the building (Table 7) and the supply from the two rivers are shown in Figure 36.

| energy (kWh) | space heating | water heating | lighting | electronics and other appliances | demand of the apartment | demand of the building |
|---|---|---|---|---|---|---|
| winter | 5711 | 3000 | 9502 | 6787 | 25001 | 50001 |
| summer | 0 | 1167 | 3237 | 2312 | 6716 | 13432 |
| year | 5711 | 4167 | 12739 | 9099 | 31716 | 63433 |

*Table 7: Distribution of the energy demand of each apartment*

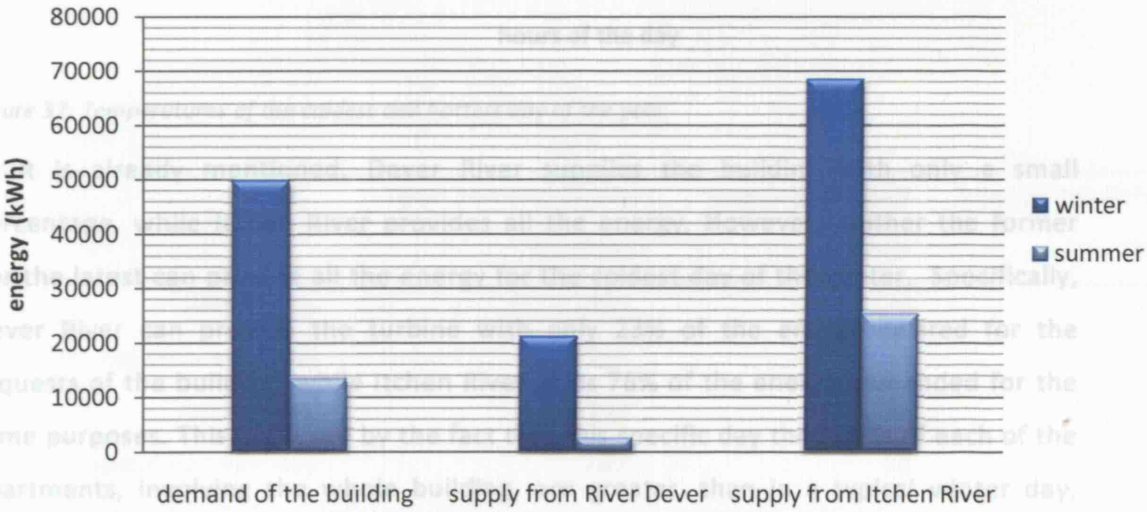



*Figure 36: Seasonal energy demand of the building and supply from the rivers*

River Dever can supply 42% of the building's annual energy demand during the winter period, when the flow is high. In the dry season, when there is not enough water to run the turbine at full flow, it can only provide 19% of the energy needed. On the other side, the building takes all its energy required to fulfill all its needs for serving both apartments, from Itchen River. More specific, the building needs just 73% of the energy supplied by Itchen River during winter days, and almost half of it (53%) during summer. This happens because Itchen River has a higher flow rate than River Dever.

Last but not least, it is interesting to mention what happens during the hottest and coldest day of the year. Temperatures of both days are presented in Figure 37. During winter's coldest day temperature ranges from -1°C to -8°C, while in the summer's hottest day it fluctuates from 8-30°C.

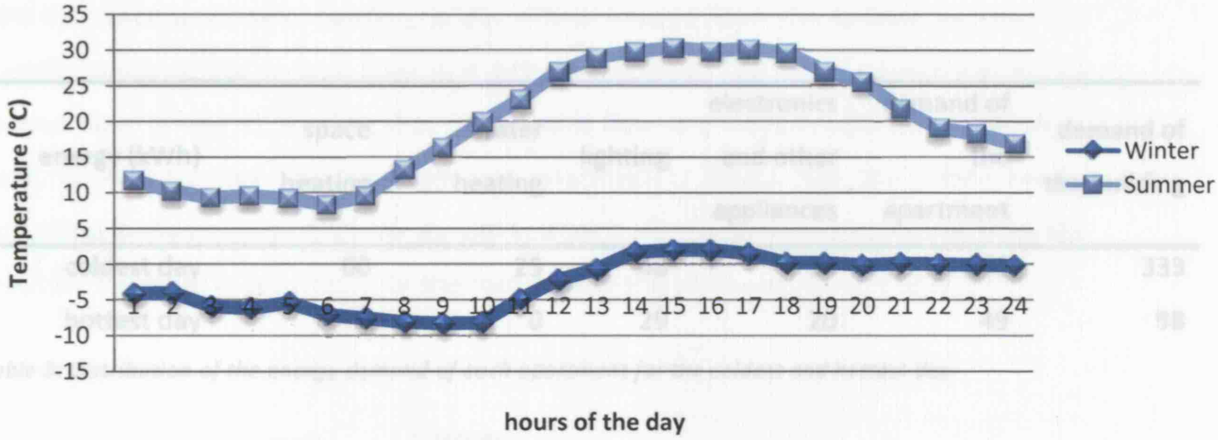



*Figure 37: Temperatures of the coldest and hottest day of the year*

As it is already mentioned, Dever River supplies the building with only a small percentage, while Itchen River provides all the energy. However, neither the former nor the latest can provide all the energy for the coldest day of the winter. Specifically, Dever River can provide the turbine with only 23% of the energy desired for the requests of the building, while Itchen River gives 76% of the energy demanded for the same purposes. This is caused by the fact that this specific day the needs of each of the apartments, involving the whole building, are greater, than in a typical winter day, when the energy from River Dever and Itchen River is 42% and 100% respectively.

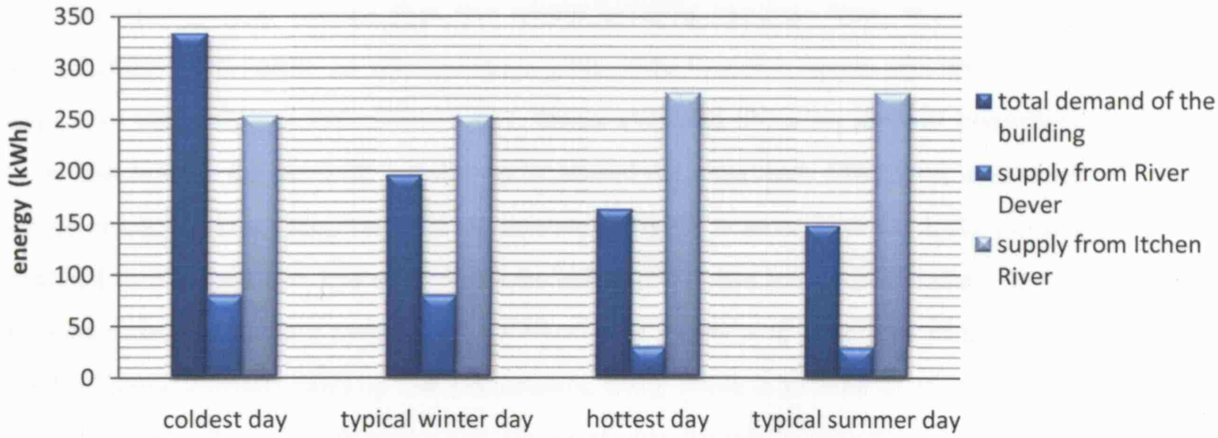



*Figure 38: Demand of the building and supply from the rivers for the coldest and hottest day of the year*

During the hottest day of the year the energy supply from River Dever is only 17%, which does not refrain much from a typical summer day, when 19% of the energy of the building is provided by the same River. On the contrary, the energy contribution to the edifice from Itchen River for the same day is 100%.

| energy (kWh) | space heating | water heating | lighting | electronics and other appliances | demand of the apartment | demand of the building |
|---|---|---|---|---|---|---|
| coldest day | 60 | 25 | 48 | 34 | 166 | 333 |
| hottest day | 0 | 0 | 29 | 20 | 49 | 98 |

*Table 8: Distribution of the energy demand of each apartment for the coldest and hottest day*

| energy (kWh) | total demand of the building | supply from River Dever | supply from Itchen River |
|---|---|---|---|
| coldest day | 333 | 78 | 253 |
| typical winter day | 195 | 78 | 253 |
| hottest day | 162 | 28 | 275 |
| typical summer day | 147 | 28 | 275 |

*Table 9: Demand of the building and supply from the rivers for the coldest and hottest day and a typical winter and summer day*

### case No 2: 6 flats for 6 couples

The building in this case accommodates 6 different flats for 6 couples. The energy that each flat demands and consequently consumes is related to the floor of the building. Energy for lighting and equipment is equally distributed to each floor; however what makes the difference is the demand for space and water heating. The first floor needs 30% for space and water heating, while 26% is needed from the turbine to fulfill the specific needs of the second floor and 44% of the third. The lower percentage of the second floor is due to the fact that flats in this floor are more comfortable related to heat, as long as they stay between two intermediate floors. The third floor needs, according to Figure 3, most of the annual energy from the turbine. This results from the fact that this floor is in touch with the roof, where the airflow is more, 1 ACH.

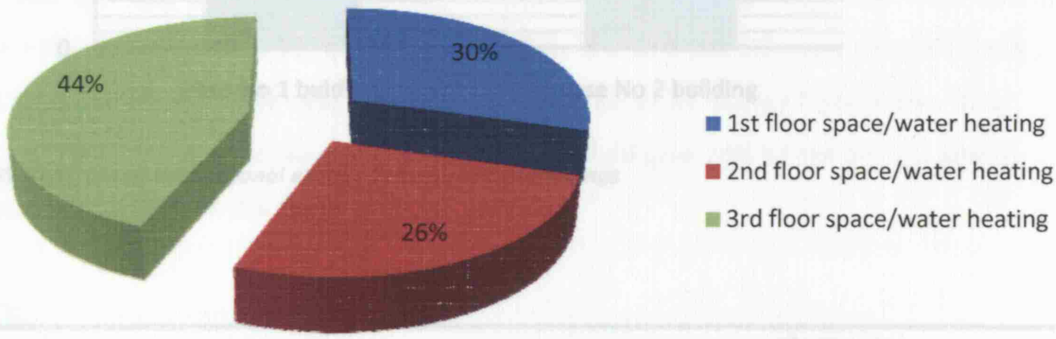



*Figure 39: Annual energy demand of each floor*

In general, the annual energy that the whole building requires from the turbine is almost 52000 kWh, while in the previous case with the two large apartments the energy was up to 64000 kWh (Figure 40). Occupancy and the area play an important role in the energy demand of a building. It would be expected, therefore, a greater need of energy in this case, because occupancy is higher than in case No 1 (12 people compared to 8). However, the occupied area differs from the previous situation. In the discussed case, there are 3 apartments of 38 m² and 3 others of 42 m², making an area of 240 m² being actually used by the inhabitants, while there is an area of 16 m² in each floor, which consist the public space and assumed unoccupied. In case No 1, there were 192 m² being fully occupied.

Dever River now provides the building with more energy, up to 52% during winter, while during summer, the rendering is also better than in the previous case arising 24%. Itchen River covers the whole energy demand of the house (Figure 41).

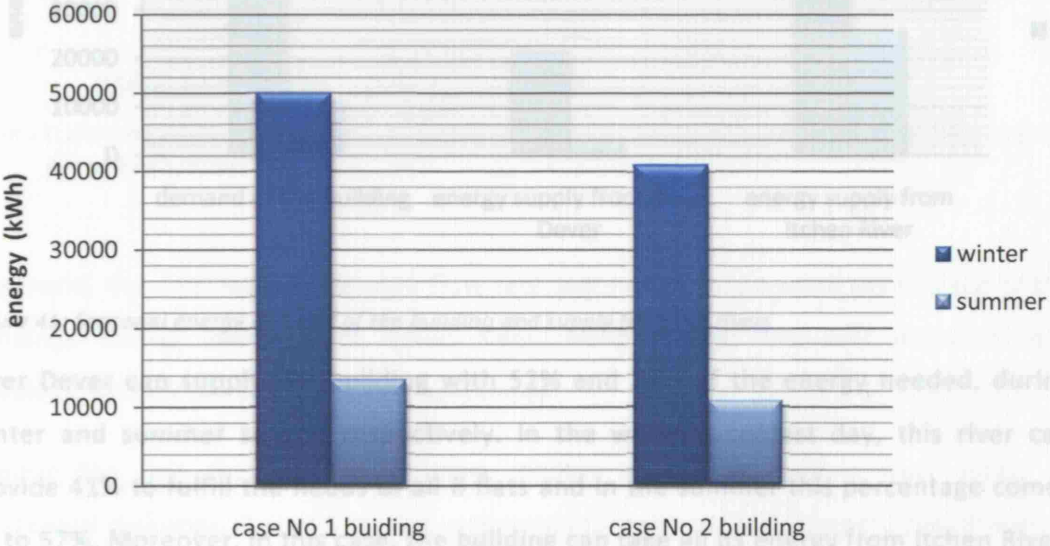



*Figure 40: Compare of the seasonal energy demand of the buildings*

| energy (kWh) | space heating | water heating | lighting | electronics and other appliances | demand of the building |
|---|---|---|---|---|---|
| winter | 9193 | 4758 | 15682 | 11201 | 40835 |
| summer | 0 | 1615 | 5342 | 3816 | 10773 |
| year | 9193 | 6374 | 21024 | 15017 | 51608 |

*Table 10: Distribution of the energy demand of the building*

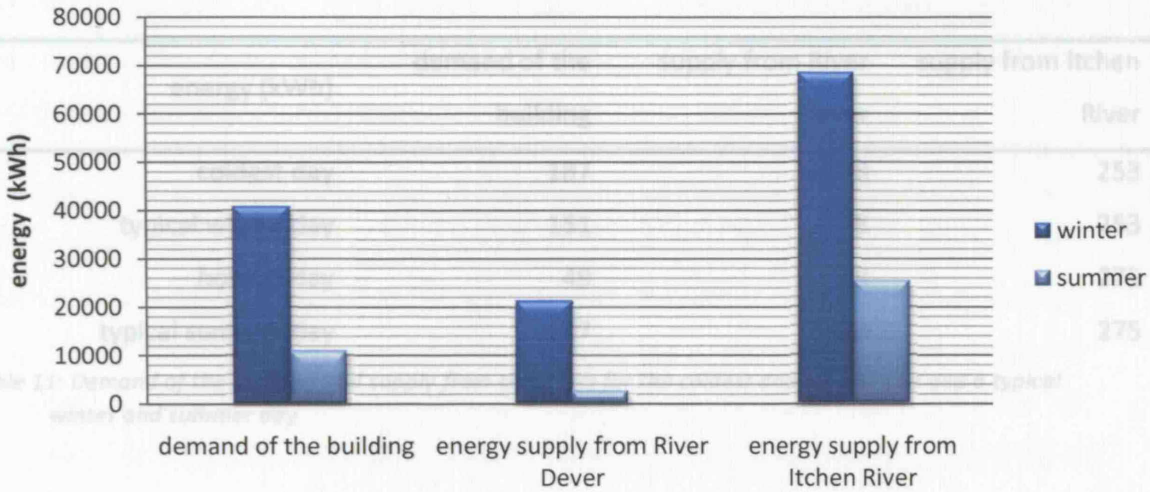



*Figure 41: Seasonal energy demand of the building and supply from the rivers*

River Dever can supply the building with 52% and 24% of the energy needed, during winter and summer season respectively. In the winter's coldest day, this river can provide 41% to fulfill the needs of all 6 flats and in the summer this percentage comes up to 57%. Moreover, in this case, the building can take all its energy from Itchen River, unlike case No 1, in which during the coldest day it could give 76% of the annual energy requirements of both of the flats.

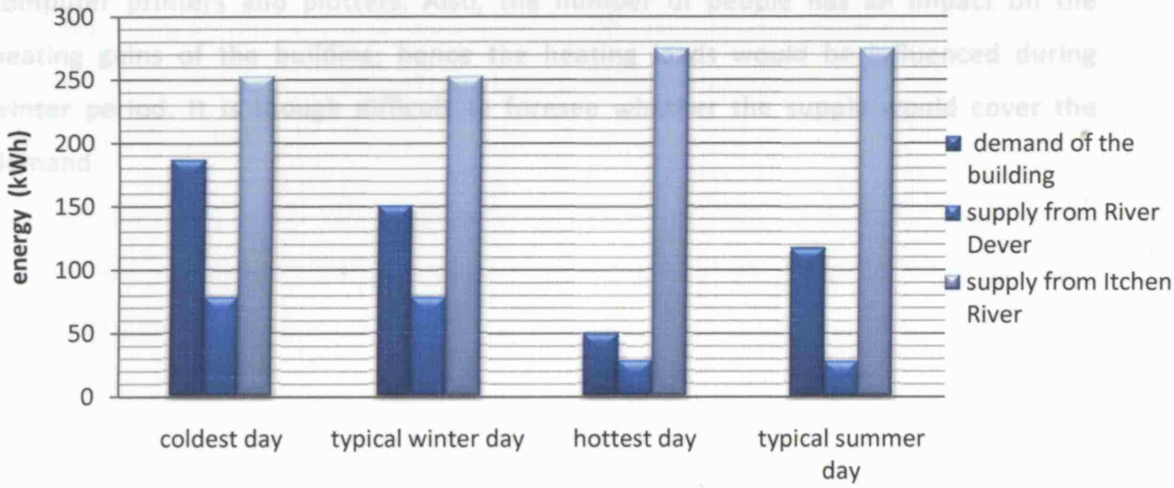



*Figure 42: Demand of the building and supply from the rivers for the coldest and hottest day of the year*

| energy (kWh) | demand of the building | supply from River Dever | supply from Itchen River |
|---|---|---|---|
| coldest day | 187 | 78 | 253 |
| typical winter day | 151 | 78 | 253 |
| hottest day | 49 | 28 | 275 |
| typical summer day | 117 | 28 | 275 |

*Table 11: Demand of the building and supply from the rivers for the coldest and hottest day and a typical winter and summer day*

In general, the river with the lowest flow rate can supply only a small percentage of the buildings' energy needs, while Itchen River, being of high flow rate, provides both buildings with all the energy that is demanded.

Despite the fact that this dissertation studies the energy supply from water in residential buildings, it would be also interested to examine and compare the efficiency of the system in an office building, where the occupancy, hours of use and energy needs differ from residential. Offices operate during the day, while they have high occupancy levels. Most of the time, the energy needs come from computers, laptops, computer printers and plotters. Also, the number of people has an impact on the heating gains of the building; hence the heating loads would be influenced during winter period. It is though difficult to foresee whether the supply would cover the demand.

# chapter 6
# conclusions

The United Kingdom has a wide variety of wetlands served by the innumerable rivers and streams that flow through the country. Generating energy from water could be proper sustainable energy strategy.

According to the study, improving old watermills could help to control the energy consumption. More specific, old watermills could replace their wheels with turbines, which would provide the appropriate energy from the water. UK rivers with average flow rate between 1.0 $m^3/s$ and 5.50 $m^3/s$ could help make these buildings naturally powered. Specifically, a typical river of a mean flow rate of 5.40 $m^3/s$ can provide all the energy of a residential building with a 300 $m^2$ occupied area, and still power from water can be stored for later use. However, as much the average flow rate decreases, so does the supply. Let's take for instance a river with a flow rate of 1 $m^3/s$, like Dever River. There is only little supply to cover all energy needs of the building. Therefore, installing a turbine in a house should be thought thoroughly, as there must be sufficient water in the location of the installation.

Apart from water, there are some other aspects that should be examined before installing a turbine. The cost of the upgradation might be high and the payback period may be long, especially if the supply does not meet the energy demand of the building. Maintenance of the turbine might be also expensive and a tiring procedure, as it should be done regularly. Sand, gravel, leaves and sticks transferred from the river should be cleaned every day, as it is something that could decrease the efficiency of the turbine, thus affect the supply.

Last but not least, the environmental issues should be considered. Sometimes, during the installation period they can affect the ecology of an estuary, and during the operation, they can lead to serious flooding.

# chapter 7

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# chapter 8

# appendices

external wall: SOLID BRICK WALL - INSULATED

| layer | M-code | width (mm) | description |
|---|---|---|---|
| inside | plaster, dense | 13.0 | DENSE PLASTERWORK, 13mm THICK |
| 2 | am1 ins\2 | 80.0 | GLASS FIBRE 2*3 |
| 3 | brick | 225.0 | 225mm LAYER OF BRICK (OUTER LEAF) |

*Tab. 1: Construction materials for the external walls of the mill*

external wall: width 318mm

| | flow direction | U-value (W/m²C) |
|---|---|---|
| external | | |
| | horizontal | 0.361 |
| | upward | 0.365 |
| | downward | 0.356 |
| internal | | |
| | horizontal | 0.350 |
| | upward | 0.357 |
| | downward | 0.340 |

*Tab. 2: U-value table for the external wall of the mill*

internal wall: TF – PARTYWALL

| layer | M-code | width (mm) | description |
|---|---|---|---|
| inside | PLASTERBOARD (WALLBOARD) | 13.0 | PLASTERBOARD (WALLBOARD) |
| 2 | MIN WOOL QUILT | 50.0 | MINERAL WOOL QUILT, 50 mm THICK |
| 3 | PLASTERBOARD (WALLBOARD) | 13.0 | PLASTERBOARD (WALLBOARD) |

*Tab. 3: Construction materials for the internal walls of the mill*

| internal wall: width 76mm | |
|---|---|
| flow direction | U-value (W/m²C) |
| **external** | |
| horizontal | 0.648 |
| upward | 0.661 |
| downward | 0.631 |
| **internal** | |
| horizontal | 0.612 |
| upward | 0.635 |
| downward | 0.583 |

*Tab. 4: U-value table for the internal wall of the mill*

| ground floor | | | |
|---|---|---|---|
| layer | M-code | width (mm) | description |
| inside | cellular glass | 100.0 | CELLULAR GLASS |
| 2 | air layer, 25mm, floor | 25.0 | AIR LAYER IN FLOOR OF 25 mm |
| 3 | conc HW 8in (HF-C10) | 100.0 | CONCRETE, HEAVY WEIGHT, 8 INC, DUBLICATE OF PREVIOUS ENTRY FOR BACKWARD COMPATIBILITY |

*Tab. 5: Construction materials for the ground floor of the mill*

| ground floor: width 225mm | |
|---|---|
| flow direction | U-value (W/m²C) |
| **external** | |
| horizontal | 0.344 |
| upward | 0.351 |
| downward | 0.339 |
| **internal** | |
| horizontal | 0.334 |
| upward | 0.343 |
| downward | 0.324 |

*Tab. 6: U-value table for the ground floor of the mill*

intermediate floor: SUSPENDED FLOOR

| layer | M-code | width (mm) | description |
|---|---|---|---|
| inside | plywood | 30.0 | 30mm FLOOR PLYWOOD |

*Tab. 7: Construction materials for ceiling and upper floor of the mill*

intermediate floor: width 30mm

| | flow direction | U-value (W/m²C) |
|---|---|---|
| external | | |
| | horizontal | 2.495 |
| | upward | 2.697 |
| | downward | 2.269 |
| internal | | |
| | horizontal | 2.038 |
| | upward | 2.321 |
| | downward | 1.752 |

*Tab. 8: U-value table for the ceiling and upper floor of the mill*

roof: PITCHED ROOF

| layer | M-code | width (mm) | description |
|---|---|---|---|
| inside | plasterboard (ceiling) | 9.5 | PLASTERBOARD (CEILING) |
| 2 | min wool quilt | 150.0 | 150mm MINERAL WOOL |
| 3 | loft space | 200.0 | ---- |
| 4 | tiles concrete | 10.0 | CONCRETE TILES |

*Tab. 9: Construction materials for the roof of the mill*

roof: width 369.5mm

| | flow direction | U-value (W/m²C) |
|---|---|---|
| external | | |
| | horizontal | 0.241 |
| | upward | 0.244 |
| | downward | 0.236 |
| internal | | |
| | horizontal | 0.236 |
| | upward | 0.240 |
| | downward | 0.229 |

*Tab. 10: U-value table for the roof of the mill*

window's double glazing: TYPICAL GLAZING

| layer | M-code | width (mm) | description |
|---|---|---|---|
| inside | clear 4mm glass | 4.0 | ---- |
| 2 | air | 12.0 | ---- |
| 3 | clear 4mm glass | 4.0 | ---- |

U-value: 2.867 W/m²C

*Tab. 11: Glazing materials of the mill*

frame of windows and doors: SOFTWOOD ALUMINIUM SPACER

| layer | M-code | width (mm) | description |
|---|---|---|---|
| inside | softwood aluminium spacer | 50 | ---- |

U-value: 2.006 W/m²C

*Tab. 12: Type of frame for the windows and doors of the mill*